A Compendium of Information on Selected Low-cost Building Materials

United Nations Centre for Human Settlements (Habitat)

Chapter 1 **Introduction** i
General reading iii

Chapter 2 **Burnt-clay bricks and tiles** 1
2.1 Introduction 1
2.2 Raw materials 1
2.3 Production technologies 1
2.4 Performance standards 3
2.5 Uses in construction 5
2.6 Innovations in manufacture and use 5
Further reading 9
Equipment manufacturers and suppliers 10

Chapter 3 **Soil construction** 11
3.1 Introduction 11
3.2 Raw materials 11
3.3 Production technologies 13
3.4 Performance standards 17
3.5 Uses in construction 17
3.6 Innovations in soil construction technology 18
Further reading 24
Equipment manufacturers and suppliers 25

Chapter 4 **Low-cost binders** 27
4.1 Introduction 27
4.2 Raw materials 27
4.3 Production technologies 29
4.4 Performance standards 35
4.5 Uses in construction 37
4.6 Innovations in low cost binder technology 40
Further Reading 47
Equipment manufacturers and suppliers 49

Chapter 5 **Fibre concrete roofing** 50
5.1 Introduction 50
5.2 Raw materials 50
5.3 Production technolgies 51
5.4 Performance standards 53
5.5 Uses in construction 55
5.6 Innovations in FCR technology 56
Further reading 60
Equipment manufacturers and suppliers 61

Chapter 6 **Timber** 62
6.1 Introduction 62
6.2 Timber resources and suitability 62
6.3 Processing technologies 63
6.4 Performance standards 72
6.5 Uses in construction 74
6.6 Innovations in timber technology 75
Further reading 79
Equipment manufacturers and suppliers 80

Chapter 7 **Technology transfer and adaptation** 83
7.1 Research and training organisations 84
7.2 Development and application organisa-tions 91
7.3 International organizations 95

Bibliography 96

Chapter 1

Introduction

The supply of low-cost but durable building materials is almost universally recognized as one of the major obstacles to improved housing conditions in developing countries, whether in the cities or in the rural areas. It is also widely agreed that the establishment of high-technology building materials industries on the model of the industrialized countries can make only a very limited contribution to meeting the immediate and future needs of the developing world.

Recent experience is that the capital costs of such industries are too great to allow the production of materials at a price which the ordinary citizen can afford; they have frequently also resulted in large unrepayable foreign exchange burdens, and have required continued dependence on imports for maintenance, fuel and even raw materials. As a result there is a growing interest in the use of materials which can be produced entirely from local resources, using simple small-scale production technologies, to provide durable building materials at a cost which can be afforded by the mass of potential housebuilders.

Most of these materials are already well-known and in many countries there are established production technologies, but they have been disregarded or rejected because they have been thought to lack the properties of strength, water resistance or durability required for fully permanent construction, or because existing standards and specifications have not permitted their use. Yet, as a result of considerable development, many projects and much experience in recent years, it has been effectively demonstrated that materials such as burnt-clay bricks, adobe or stabilized soil, lime-based cements and timber, if carefully selected, processed and applied, can be as satisfactory as factory-made materials such as Portland cement, cement-based blocks or steel sheet roofing, and can be made available at reduced costs. There are other newly developed materials too, such as rice-husk ash cement, sulphurcrete blocks and fibre- concrete roofing which can provide satisfactory alternatives without involving costly processing plants or the import of raw materials or equipment.

The spread of these technologies has not been as rapid or as extensive as the urgent housing situation requires. There are reasons for this, one of which is the need to break down prejudices against them on the part of building authorities and professionals. Others may be that the large-scale commercial organizations involved in the building materials industry do not believe their interests will be served by a proliferation of small-scale production units, and that commercial interests have so far done little to promote or transfer these technologies. Another is that there has been a lack of apprpriate information about these technologies for the small-scale entrepreneur or co- operative which might benefit from them. The purpose of this compendium is to bridge to this gap by assembling information on a range of building materials technologies which have the potential to improve the low-income housing situation in developing countries. The report concentrates on five different categories of materials: burnt-clay bricks and tiles, soil construction, low-cost binders, fibre-concrete roofing, and timber. The choice of materials is by no means comprehensive - stone and thatch, for instance, are important materials that have not been included. What the materials chosen all have in common is that they are derived from very widely available raw materials, they can use relatively simple low-cost processing technologies, and they have been the subject of recent research and development work in many different developing countries.

The compendium is intended to be of use to organizations or individuals wishing to acquire and make use of the technologies for the production of building materials, rather than for designers or users of materials. There is therefore a strong emphasis on production technologies and on performance standards which should be achieved to meet the needs of the user, with only brief treatment of technical details of the way the material is used in building. The compendium lists commercial organizations which provide, install or advise on the equipment and plant required for the establishment of production. It should be noted that these lists are by no means comprehensive and that the inclusion of the name of any organization in these lists does not imply any recommendation by either the authors of this report or UNCHS (Habitat).

A particular feature of the compendium is that it draws attention to current or recent innovations in the technology of production and use of the materials covered. In this context, "innovation" refers to applications of building materials technology, either in the use of particular raw materials, of particular production techniques, or of particular applications which are entirely new, or unfamiliar in the context in which they have been introduced. The innovations described are at different stages of development; some of them are still at a laboratory stage, or have been subject to limited field testing; others are pilot projects; others have been more widely replicated in a particular country or geographical region. The descriptions of these innovations are largely drawn from the reports of the organizations responsible for them, and an independent assessment is not feasible except in a few cases. Where possible, the status of the innovation, whether laboratory, pilot project or fully commercialized, is indicated. Innovations which are still at the level of materials science are not considered as a high proportion of these may never find technological application.

Another feature of the compendium is an attempt to indicate the energy consumption involved in the production of the materials covered. Not only is energy, in the form of fuels and electricity, one of the principal costs in the production of many materials, it is an increasingly scarce resource in many countries. The need to conserve energy applies both to commercial fuels and to non-commercial fuels such as locally grown firewood or agricultural waste. Choice of building materials production technology must take account of the energy requirements of materials. Technological innovations which either conserve fuel, or replace a scarce fuel with a more abundant one, or which replace a high-energy material with a low-energy one without any reduction in standards of performance, are of particular importance for the future, and such innovations will be highlighted in this compendium.

The compendium is organized in five chapters, each covering one of the categories of building materials, and a final chapter, which summarizes information about the organizations involved in technology transfer. The chapters on building materials are each divided into eight sections. A brief introductory section attempts to define, and describe briefly the range of materials or technologies covered; the next section describes the raw materials requirements, and any raw materials testing normally needed. The range of production technologies is then discussed, with emphasis particularly on the simple small-scale technologies, and on the equipment needed at each stage of the production process. The next section covers production standards, indicating the properties which the material needs to have for application in building, the tests by which those properties are measured, and the level of performance which is required by existing or proposed standards. A further section discusses the range of uses of the material in building, with emphasis on comparison with alternative materials, and on particular limitations or specially favourable applications.

Innovations in raw materials, in production technology or use, other than those previously covered, are dealt with in the subsequent section. The last two sections in each of these chapters document bibliographical references and plant and equipment suppliers associated with the particular material.

The final chapter lists the organizations involved in technology transfer in the field of low-cost building materials in three separate categories, namely research and training organizations, development and application organizations concerned with actual field projects, and international organizations mainly concerned with documentation and information dissemination. Brief notes on the scope of the activities of each organization are also given.

This compendium has been compiled with the expert assistance of two principal consultants. UNCHS (Habitat) is particularly grateful to Dr Robin Spence of Cambridge Architectural Research Ltd, and to Mr Lionel Jayanetti of the Timber Research and Development Association (TRADA), United Kingdom.

General reading

African Regional Organization for Standardization, Commonwealth Science Council and United Nations Centre for Human Settlements (Habitat), *Standards and Specifications for Local Building Materials*, Report of the ARSO/CSC/UNCHS Workshop on Formulation of Standards and Specifications for Local Building Materials, Nairobi, 16-24 March 1987 (London, Intermediate Technology Publications, 1987).

Dancy, H.K., *A Manual of Building Construction* (London, Intermediate Technology Publications, 1975)

Davey, N., *A History of Building Materials* (Phoenix House, 1961).

Everett, A., *Materials* (London, Mitchell, 1986).

Government of Kerala, *A Performance Approach to Cost Reduction in Building*, Expert Committee Report (Trivandrum, 1974).

International Council for Building Research, Studies and Documentation, and International Union of Testing and Research Laboratories for Materials and Structures, *Appropriate Building Materials for Low Cost Housing*, Conference Proceedings, 2 vols (London, E. and F.N. Spon Ltd., 1983, 1985).

———, *Building Materials for Low Income Housing*, Bangkok Conference Proceedings (Bangkok, 1987)

Pama, R.P., Nimitongskul, R., and Cook, D.J. (eds), *Materials of Construction for Developing Countries*, Conference Proceedings (Bangkok, Asian Institute of Technology, 1978).

Spence, R.J.S., and Cook, D.J. *Building Materials in Developing Countries* (Chichester, John Wiley and Sons, 1984).

Stulz, R., *Appropriate Building Materials* (London, Intermediate Technology Publications, 1983)

United Nations Centre for Human Settlements (Habitat), *The Use of Selected Indigenous Building Materials with Potential for Wide Application in Developing Countries* (Nairobi, 1985) (HS/83/85/E).

United Nations Industrial Development Organization and United Nations Centre for Human Settlements (Habitat), *First Consultation on the Building Materials Industry* (Vienna, 1985).

Chapter 2

Burnt-clay bricks and tiles

2.1 Introduction

Burnt-clay bricks and tiles are made by forming a plastic mixture of a suitable soil and water into appropriately shaped units, drying the units and then firing or burning them in a kiln. A huge variety of building products is made in this way, including solid bricks and blocks, hollow bricks and blocks, roofing tiles of many different shapes, and floor tiles and pipes, among others. This compendium will be concerned only with the manufacture of two basic items, solid bricks and pressed roofing tiles.

A wide variety of technologies is available, both for processing of raw materials and for firing, ranging from simple small-scale labour-intensive processes to large-scale capital-intensive processing plants. The emphasis will be on the simple, low- capital techniques. The manufacture of burnt-clay building products is energy intensive, and thus emphasis will be placed on means to reduce energy consumption or use low-grade fuels.

2.2 Raw materials

A wide range of soils is suitable for the manufacture of clay bricks and tiles. The essential property is plasticity, the ability to be moulded or shaped by pressure or working, which is imparted by clay particles. The proportion of clay needed to impart sufficient plasticity is not very large, and soils with a large clay content often exhibit too much shrinkage which causes cracking and distortion. Alluvial soils are most commonly used for brickmaking, and the Indian Standard IS:2117 gives the following preferred soil composition (by weight):

Clay 20 to 30 per cent
Silt 20 to 35 per cent
Sand 35 to 50 per cent

The total weight of the clay and silt particles together should preferably not exceed 50 per cent. Where a soil with these properties is not available, mixing of two soils, or the admixture of sand, or ash, or finely ground fired clay (grog) can be used to obtain a suitable particle size distribution. Special techniques are needed for the pretreatment of black cotton soils (see section 2.6).

Indian Standard IS:2117 also gives a preferred plasticity index (PI) between 15 and 25 per cent. The soil grading and plasticity properties are found by the use of the particle size distribution and plasticity tests described in section 3.2.

Drying and firing shrinkage are other properties which are important to the performance of a brick clay. They are measured as the average change in linear dimension at the end of the drying and firing stages, compared with the as-moulded brick or tile. Typical values of up to 7 per cent for drying shrinkage and between 6 and 8 per cent for firing shrinkage (UNIDO/ILO, 1984) or between 8 and 15 per cent for total shrinkage (IS:2117) have been given, but these are only indicative.

In tilemaking, a higher dry strength and a lower porosity is required than for brickmaking, and a soil with more clay particles and less sand is required - but precise requirements depend on the processing technology. For both brickmaking and tilemaking, testing of raw materials has only a limited usefulness, as good test results cannot guarantee that a soil will be suitable in practice. Thus production trials at a small scale, for example by transporting raw materials to an existing production plant, are advisable before making any investment decisions.

Certain common ingredients of clays or brick-earths are desirable, such as iron oxides which are responsible for the colour (yellow, brown, red or blue) of the fired clay products. Other impurities are undesirable. Limestone ($CaCO_3$) is a common impurity which is undesirable if it occurs as nodules in the soil: these will be converted to quicklime during firing, which can subsequently expand and cause cracking of the bricks. An upper limit of 1 per cent CaO or MgO is desirable for alluvial soils. Sulphates and other water soluble salts should also be limited, as they can cause efflorescence or white staining of the bricks; an upper limit of 1 per cent is desirable.

2.3 Production technologies

The principal stages in the production of burnt clay products, whether bricks or tiles, are:

(a) Winning,
(b) Preparation,
(c) Moulding,
(d) Drying;
(e) Firing.

Winning and preparation

Except in large-scale mechanized brick production plants, the brick-earth is normally won from workings not exceeding 3 m deep, and hand-tools such as pick-axes, shovels and wheelbarrows or head-baskets are suitable. The use of shallow workings has the additional advantage that the land can be returned, after removal of the brick-earth, to agricultural use. The preparation of the soil involves screening, crushing, weathering and tempering.

Crushing may be required if a heavy clay soil is to be used. Crushing with manual tools is laborious, and normally mechanically powered roller-crushers are used, but manually powered crushing equipment is available (see section 2.6). Screening involves the removal of all gravel, sand, vegetable matter and lime nodules exceeding about 2 mm; hand screening is usually used. Weathering is often required in order to develop a homogeneity in the mass of the soil, and to eliminate some impurities through oxidation or leaching. Where used, it involves leaving the soil in heaps exposed to the weather for several weeks, spraying with water if needed, and turning it over to expose the whole heap.

Tempering involves mixing the soil with water, up to the required water content, in layers up to 30 cm, and allowing it to soak to ensure thorough dispersion for about 36 hours. Before moulding the soil is kneaded or mixed with spades or mechanical equipment into a plastic mass. Treading with the feet, using human or animal labour, is another means of kneading the soil. At this stage any additions to improve the soil properties are made. Alternatively (or as an addition) a pug-mill may be used in the preparation process for mixing and kneading the raw materials. Pug-mills may be animal-driven or manually or mechanically powered.

Moulding and drying

In traditional brickmaking, bricks are moulded by hand in simple wooden moulds. The soil is formed into a clot or lump of appropriate size, and thrown into the mould with sufficient force to take up its shape accurately. The excess is scraped off. The mould is then removed leaving the brick to dry. To ensure clean re-use of the mould, two different techniques are used. *Slop moulding* involves keeping the mould wet, and adding sufficient water to prevent sticking; *sand moulding* involves rolling the clot in sand (or ash) before moulding to aid release. In either method moulding may take place on the ground or at a table. Multiple or gang moulds can be used to speed production. Tiles can also be moulded manually, using methods similar to slop or sand moulding, although normally more manipulation of the clot is required to shape the soil to the more complex shape of the mould.

Bricks and tiles can be moulded mechanically by means of an extrusion process. The clay after mixing is forced through a die into a clay column which is then sliced by wires into brick- shaped pieces, or in the case of pressed tile manufacture, rectangular "blanks". Tile-moulding is then completed by pressing the blanks in a hand operated or mechanically powered fly-press or other pressing device. Extrusion processes require a smaller water content for moulding and, therefore, produce a denser brick or tile, which will also be stronger in the green state after moulding. Extrusion also permits the formation of perforated bricks.

In dry climates (or where brickmaking is a seasonal activity), bricks and tiles are sun-dried. Covering or shading is normally needed to prevent rapid early drying; when they are strong enough, bricks may be built into stacks (or "hacks") to reduce the space used. Tiles normally remain in their moulds for the earliest stages of drying. When they have gained sufficient strength they are stacked on edge for further drying. In wet climates, covered drying sheds may be needed. Drying rates can be improved by using the waste heat from the firing process. In tilemaking processes especially, controlled drying is essential to eliminate the tendency to cracking. The drying process can take several weeks, so substantial space is required, whether covered or sundrying is to be used.

Firing

The simplest technique used for firing bricks is a *clamp*. A *clamp* is a large pile of bricks carefully stacked to leave spaces for fuel and for the distribution of the hot gases. The lowest layer of a clamp consists of a pattern of already burnt bricks with fuel (normally small coal or coke) spread between them. Dried unfired bricks are then stacked on edge in layers above this, up to about 30 layers; the kiln is completed with an insulation layer of fired bricks. Additional fuel may be placed in a further layer at a higher level in the kiln. The sides of the kiln are sloped to maintain stability; thus no permanent structure is required. Firing is initiated by firewood set in specially constructed eyes at the lowest level, and continues until all fuel is burnt, which may take several weeks. Long clamps are sometimes constructed in which the firing begins at one end while the setting of bricks is still in progress at the other. The number of bricks in a clamp may range from 10,000 to 100,000 or even more, the larger sizes being more efficient. The properties of the bricks will also vary, with better burned, strong bricks towards the centre of the kiln, and softer bricks at the edges, so that some sorting is needed before the bricks are sold.

An adaptation of the clamp used where firewood is the available fuel is the scove kiln, which incorporates tunnels through the base of the kiln to feed fuel continuously during firing; setting of the bricks is also less dense and the outside of the kiln is normally plastered with mud to reduce heat loss, leaving "chimney" openings at the top. Clamps and scove kilns have been described by UNIDO/ILO (1984) and a manual for the construction of a scove kiln published by Thomas (undated). They are suited only for firing bricks, rather than tiles. Simple kilns sometimes have some permanent surrounding structure which incorporates fireholes. This improves insulation and provides an opportunity for covering for protection from rain. Such kilns are called *scotch kilns;* they can be used for firing tiles as well as bricks. All the above kilns are *updraught* kilns. *Downdraught kilns* are completely enclosed by a permanent structure, usually of brick, either circular or rectangular in plan; the hot gases from external fires are deflected downwards from the arched roof of the kiln, and drawn down through the bricks, through holes in the floor of the kiln, and exhausted through a chimney. Downdraught kilns can be better controlled than the other types described and are suitable for the manufacture of tiles as well as bricks since less weight is carried by the clay products themselves. They are also somewhat more fuel-efficient and any type of fuel may be used.

All the above kilns are intermittent; the fire burns for a period and then goes out so that all the heat generated is subsequently lost. Much greater fuel efficiency can be achieved by the use of continuous kilns in which the fire burns continuously and into which bricks or tiles are continuously loaded and unloaded. In Hoffman kilns and Bulls Trench kilns, the firing zone of the kilns progresses slowly around a circular tunnel or trench; green bricks or tiles are loaded ahead of the fire and fired ware is unloaded behind it. Heat exchange is facilitated by incorporating a preheating zone in which the unfired bricks are heated by the hot gases flowing from the firing zone, and by a cooling zone in which the cold air drawn into the firing zone is warmed by the heat from the already fired ware. The air and gas flow is maintained by a system of ducts and dampers both within the stacked ware and in the permanent structure of the kiln. The gases are exhausted through chimneys. A large number of variants of this kiln type are in use. They have a much greater fuel efficiency than intermittent kilns and produce a better uniformity of product than the simpler types of intermittent kiln. The Bulls Trench kiln, used widely in South Asia for brick-burning, has a permanent structure consisting solely of brick sidewalls; moveable chimneys are placed on top of the bricks in the firing zone, and a layer of ash is used for insulation. More advanced designs of this kiln type have fixed brick chimneys. Some discussion of these variations and their effect on fuel efficiency is given in section 2.6.

A more sophisticated continuous kiln is the tunnel kiln, in which the firing zone is stationary, and the ware (bricks or tiles) is slowly moved through it on rail cars. This type of kiln is very capital intensive, and generally uneconomic for the firing of simple bricks and tiles.

Fuel and energy consumption

The amount of fuel needed for the production of clay bricks and tiles depends on the kiln type on the type of fuel being used, and on the type of bricks or tiles produced. In general, it can be expected that continuous kilns will have a lower fuel consumption than intermittent kilns, and that the fuel required per unit weight of fired clay will be greater for tiles than for bricks. Some indicative figures are given in table 2.1 for brick production.

It will be seen that the fuel consumption (in terms of heat required) in wood-fired scove kilns is over three times that of continuous Hoffman or trench kilns. The energy-intensive nature of brick production is further emphasized by comparing the energy requirement of brick and stabilized soil walling. Even the most efficient brickmaking processes require delivered energy of 3.0 MJ/kg, while soil construction requires between 0 and 1.0 MJ/kg depending on the process used.

2.4 Performance standards

Performance standards for bricks and roofing tiles have been published in many countries, and cover a range of products.

Bricks

Standards for solid bricks normally specify limits on dimensional tolerances, compressive strength, water absorption, and the extent of efflorescence. Some requirements for general appearance are also normally specified.

The standard size for burnt-clay bricks varies from country to country. British Standard BS 3921, derived from imperial units, and still widely used, has a format of 225 x 112.5 x 75 mm, which includes the mortar joint. With an allowance of 10 mm for vertical and horizontal joints this gives an average brick dimension of 215 x 102.5 x 65 mm. The tolerance is specified on the overall dimension of a line of 24 bricks, variations of 11.4 and 11.8 per cent are allowed in length and breadth respectively, while the height may vary between +3.8 and -1.9 per cent of the total (BS 3921). The metric standard now used in many countries has a format of 200 x 100 x 100 mm: tolerances on a line of 20 bricks

Table 2.1. Comparative fuel consumption of different brick kilns

Type of kiln	Fuel type	Calorific value (MJ/ton)	Energy per thousand bricks (MJ)
Scove (Africa)	Firewood	16 000	16 000
Clamp (India)	Coal	27 000	8 000
Bull Trench (India)	Coal	27 000	5 400
Hoffman (UK)	Coal	26 000	5 000
Tunnel	Oil	44 000	4 000

Sources: UNIDO/ILO (1984), Parry (1979) are specified as 12.1 per cent on the total of each dimension.

The compressive strength of bricks is a good guide not only to their ability to carry loads in a wall, but also to their durability. The stronger bricks (from the same source) are generally harder and more durable, while weaker bricks are generally softer and less durable. Most standards specify a range of compressive strengths, for different uses. Some standards distinguish between common bricks (for general purposes), facing bricks (selected for appearance) and engineering bricks (for heavy works or other severe conditions) and specify different load classes accordingly. The classes specified in Indian Standard IS:1077-1986 are as shown in table 2.2.

The specification of a wide range of strengths permits the most efficient use of all bricks produced in kilns in which the quality and strength varies widely. The lowest strength specified (3.5 N/mm^2) may be adequate for a wide range of uses, including external load-bearing walls of one- or two-storey buildings. The measurement of strength requires the use of compression testing machines. Standard procedures are laid down in individual standards (IS:1077-1986, Nigerian Standard No. 74- 1976, BS 3921).

Table 2.2. Classes of common burnt-clay bricks from Indian Standard IS:1077-1986

Class description	*Average compressive strength* Not less (N/mm^2)	Less than (N/mm^2)
35	35.0	40.0
30	30.0	35.0
25	25.0	30.0
20	20.0	25.0
17.5	17.5	20.0
15	15.0	17.5
12.5	12.5	15.0
10	10.0	12.5
7.5	7.5	10.0
5	5.0	7.5
3.5	3.5	5.0

The water absorption of a brick is a measure of its porosity. Some porosity is desirable, but highly porous bricks may absorb and transmit too much water and thus may swell and shrink or may lack durability. Water absorption is measured by immersing a brick in cold water for a period of 24 hours and then comparing the saturated weight with the dry weight. An upper limit of 20 per cent is specified for bricks of classes 3.5 to 12.5 and of 15 per cent for higher classes in Indian Standard, IS:1077-1986. More elaborate boiling or vacuum tests are specified in other standards but only for bricks to be used for special purposes.

Efflorescence is unsightly and may in exceptional cases cause spalling and disintegration of the faces of bricks. A test for efflorescence is to immerse bricks halfway in distilled water for two weeks. If soluble salts are present, they will dry out on the top corners of the brick as the water is being soaked up. As long as only slight efflorescence occurs, the bricks are considered adequate (IS:1077-1986, UNIDO/ILO 1984). Tests may also be specified for lime-blowing (hydration of quicklime in the bricks derived from limestone nodules in the soil), for frost resistance, or for general appearance. Indian Standard, IS:1077-1986, specifies that bricks should be "free from cracks or flaws, and nodules of free lime"

Tiles

Tests for roofing tiles differ considerably from those for bricks. Detailed specifications are given of required dimensions and dimensional tolerances. Mangalore tiles (IS:654-1977) are specified by the overall dimensions in three separate sizes 410 x 235 mm, 420 x 250 mm and 425 x 265 mm with tolerances on a line of three tiles of 11.5 per cent on length and 12.4 per cent on breadth. These tolerances allow for minimum overlaps of 60 mm lengthwise and 25 mm widthwise. Upper and lower limits on oven-dry weight are specified (less than 3 kg, and more than 2 kg for six tiles) in place of a thickness specification. The location and size of fixing lugs and holes are also specified.

Bending strength is more important than compressive strength and is measured by a breaking load test, in which a tile is supported between two parallel steel bearers 250 mm while a load is applied through another parallel steel bearer at the mid-point and gradually increased until failure occurs. The average breaking load for six Mangalore pattern tiles of dimensions 410 x 235 mm should not be less than 80 kg (for class A). A higher class (class AA) with a minimum average breaking load of 110 kg is also specified. Minimum breaking loads of 68 kg and 90 kg for individual tiles are also specified. There are different specified breaking loads for tiles of other sizes. Water absorption is measured in the same way as for bricks; the average for a sample of six tiles should not exceed 24 per cent and 19 per cent in classes A and AA respectively (IS:654-1977).

A separate permeability test is also specified for tiles, to ensure that water does not pass through them. A tile is placed in a rectangular trough with the same plan dimensions as the tile. The edges of the tile are sealed with wax or bitumen to prevent leakage and the trough is filled with water to a depth of 50 mm above the lowest level of the tile surface. The bottom of the tile is examined after six hours for dampness indicating water seeping through (IS:654-1977).

The standard tests described above are normally carried out in testing laboratories specified by clients or run by government agencies, although some large brick and tile works are equipped with their own testing facilities.

Simple field tests may also be used for checking the adequacy of bricks and tiles more widely. The tests for general quality, surface appearance, absence of twist, and impurities such as large particles visible in the surface can be done without any equipment. The adequacy of burning can be tested by striking bricks or tiles, which should give a characteristic ringing sound. Badly underfired bricks can also be detected and eliminated by soaking them in water for at least 24 hours, after which there should be no softening or swelling.

2.5 Uses in construction

Clay bricks

Brickwork made from burnt clay bricks laid in a lime, lime-pozzolana or cement-based mortar is an ideal walling material in almost any climate. It is strong and durable, and it is amenable to a variety of configurations, surface treatments and textures through the use of different brick bonds. It can be used in a single skin (100 mm thickness) where loads are light and thermal mass should be reduced (as in the hot humid tropics), or in the form of a 200 mm solid or 2x100 mm cavity wall with insulation where good insulation is required. For use in earthquake areas, it can be reinforced longitudinally by mesh reinforcement in mortar courses, and the use of a 300 mm wall of Quetta bond (Spence and Cook, 1984) permits the use of vertical reinforcement in mortar columns between the two skins of brickwork.

Other advantages over alternative cement-based walling materials are:

(a) Burnt-clay bricks are more dimensionally stable than cement-based blocks, and walls built with them are not susceptible to shrinkage cracking (although temperature movements need to be controlled as in the other materials);

(b) The surface durability and attractive appearance eliminate the need for plastering or other renders, although these can be used if desired;

(c) The brick format permits the use of brick arches or corbelling to span door and window openings or patterns of openings in walls can be used (in hot humid climates) to replace door and window openings;

(d) Well burnt brick can safely be used in contact with the ground, in foundations, paving and flooring. Ceramic tiles of other formats can also be produced for paving and flooring. These uses are covered by national standard specifications and codes of practice which are outside the scope of this compendium.

Burnt-clay bricks are also suitable for use in load-bearing walls for multi-storey buildings. The selection of brick strength, mortar type and wall configuration for load-bearing walls is covered in national standards. As for other masonry materials the use of brickwork in walling requires careful detailing. At the top, a wall-plate or bond-beam is needed to distribute the load into the wall. Gutters or overhanging eaves are required to protect the wall from running water. A damp-proof course is required to eliminate rising damp.

Clay tiles

In spite of the competition from cement-based roofing tiles, burnt-clay tiles continue to be very widely used wherever suitable soils are found. Well made clay tiles can have a life exceeding 50 years with little or no maintenance, and they maintain their colour better than pigmented concrete tiles. The correct use of any particular tile in roofing is generally governed by local tradition, well known to roofing craftsmen, and sometimes set out in national standards (e.g. IS:2858-1964 *Code of Practice for Roofing with Mangalore Tiles, BS 402: 1979 Specification for Plain Clay Roofing Tiles and Fittings). Careful consideration needs to be given to:*

(a) Pitch of roof (there is a minimum and maximum pitch for each tile);

(b) Lapping of tiles, both at ends and at the sides;

(c) Protection of verges and eaves from wind uplift (e.g. with steel ties);

(d) Detailing of ridges, hips and valleys (usually with special tiles);

(e) Provision of drainage by guttering etc.;

(f) Roof construction to ensure sufficient strength and stiffness.

Generally, clay tiles have been used in conjunction with sawn-timber roof structures. Bamboo trusses and purlins and battens may be used if the tiles are tolerant of the larger roof deflections involved, for example with handmade pantiles. In some areas clay tiles are used in conjunction with concrete roofs, or to cover earth roofs.

In Kerala, India, where the Mangalore tile industry is well established, a new use for the cracked or broken rejects of the tile factories has been devised by a local architect, Laurie Baker, as a filler in reinforced concrete floor slabs.

A stack of two or three tiles is cast into the underside of the slab, between concrete ribs, replacing more expensive concrete, increasing the insulation, and simultaneously reducing the weight of the slab. Broken tiles may also be ground in a hammer mill to produce a burnt-clay pozzolana.

2.6 Innovations in manufacture and use

Given the energy intensity of brick manufacture, it is not surprising that much recent innovation has concerned the design of kilns to improve energy efficiency or to make use of unconventional, biomass or low-grade fuels. Innovation has also been directed towards the pretreatment of difficult soils to make them suitable for brickmaking and towards improvement in brick and tile processing plants. Some innovation in the use of bricks and tiles in construction in new ways has been taking place. In general, recent innovation has tended to concentrate on bricks rather than tiles, although there appears to be no very good reason for this trend.

Use of difficult soils

The so-called "black-cotton soils" present considerable difficulty for brickmaking. They contain a high proportion of clay minerals which are particularly susceptible to moisture movements and which cause severe distortions and cracking during drying and firing. Indian Standard IS:2117-1986 proposes the following method of pretreatment. The clay is first washed clean of lime nodules in tanks. The clay slurry is then run into settling tanks from which, after three or four days, the water is removed by bucket. Fine coal-ash grog is then added (up to 30 to 40 per cent by weight of the clay), with an addition of 0.5 per cent of sodium chloride (common salt) to prevent lime bursting. The clay is then thoroughly mixed with the grog and allowed to dry for a further period of up to three or four days until the correct moulding consistency is attained. The grog is prepared by lightly firing lumps of black cotton soil in a clamp at about 700 to 750° C, using coal ash, firewood, or brushwood as fuel. The fired material is then pulverized in a hammer mill or pan- mill to a fineness of less than 2 mm.

Limestone (or "kankar") nodules can present difficulties in many alluvial soils, rendering the soil unsuitable for use below a certain depth, because of the occurrence of lime-blowing. They may be eliminated by screening or washing in a wash mill; or rendered harmless by grinding the soil to pass a sieve of 0.63 mm mesh. A third conventional solution is "docking", or soaking the bricks in water soon after the bricks are unloaded from the kiln to hydrate any quicklime.

All these solutions are expensive or cumbersome. Two more recently developed solutions are: (a) the addition of 0.5 to 0.75 per cent of sodium chloride at the time of mixing or pugging; and (b) the addition of 5 to 10 per cent coal ash to the clay before moulding, and firing at 900°C, in which case the calcium oxide formed will be of porous structure.

Kiln design and fuels

In South Asia, fired-clay brick and tile manufacture is a long-established technology, but it faces problems because of the increasing scarcity and high price of fuels. This has stimulated considerable recent innovation in the subregion in methods of reducing the fuel consumption of kilns.

In some areas small clamp kilns are common, which were traditionally fuelled by firewood. In Indonesia the use of rice husk as a fuel is common, often in conjunction with smaller quantities of firewood. Small clamps of around 4,000 bricks are built. A single firehole runs through the base of the kiln for the insertion of firewood, as with a typical scove kiln, but the outside of the kiln is surrounded by additional layers of unfired bricks, forming a cavity wall, with a continuous cavity which is initially filled with rice husk. Rice husks are also heaped on the top of the clamp to provide further insulation. The rice husk eventually burns, thus forming part of the fuel for the kiln, but in the initial stages of firing its high insulation value reduces heat loss from the kiln, and ensures a more even temperature distribution (Hill, 1980).

Small clamp kilns are also used in Viet Nam, with a size of 5,000 to 8,000 bricks. These are fired using fuel bricks which are moulded from a mixture of coal dust and lake mud. These are set in the brick kiln together with the unfired clay bricks. About 250 kg of coal dust is used per 1,000 bricks. The bricks have strengths ranging from 2.5 to 5 N/mm^2 (Nguyen Tien Dich, 1987).

In Zambia, methods of firing clamps without the use of firewood are being investigated at the University of Zambia. Experiments are being conducted using bundled elephant grass as fuel, compressed by means of a farm baler (Meredith, 1987).

In Northern India, where the Bull's Trench kiln technology is well established, there is extensive experimentation both with various fuels and with adaptive kiln designs (Gandhi, 1986). Traditionally, coal has been used as fuel for these kilns, but in a recent survey of over 300 kilns in the Union Territory of Delhi, Gandhi found that less than 25 per cent were only using coal; more than 70 per cent were using coal mixed with one or more fuels, usually firewood. The energy consumption of these kilns was about 10 per cent higher than those using coal only but the costs were lower. A small group of kilns was being fired entirely with either sawdust or rice husk as fuel. Energy consumption of these kilns was 15 per cent higher than coal-fired kilns, but energy costs were substantially lower.

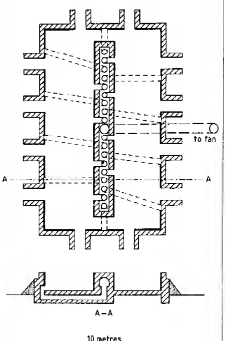


Figure 2.1 Plan of CBRI high draught kiln
Source: UNIDO/ILO (1984)

There are also developments in the design of Bull's Trench kilns. The use of fixed chimneys, with a more complex associated flue system, was introduced into India about 10 years ago. This has been shown to reduce fuel consumption by 10 to 15 per cent, at a small increase in capital costs. Higher chimneys have also been found to improve fuel efficiency. Kilns constructed recently tend to have incorporated these innovations.

Two radically different kiln designs have also been developed in order to improve draught, and reduce fuel consumption. These are the CBRI high draught kiln (Majumdar and Hiralal, 1982) (see figure 2.1), and the Habla Kiln (UNIDO/ILO, 1984). Both are designed to increase the effective tunnel length, and hence the heat exchange efficiency, by the use of zigzag chambers. The air path is longer, and the draught is forced by means of a fan. A few tens of such kilns have been built, and fuel consumption is said to be lower by about 25 per cent than conventional kilns, but the capital cost is very substantially higher, which has so far limited their diffusion (Gandhi, 1986).

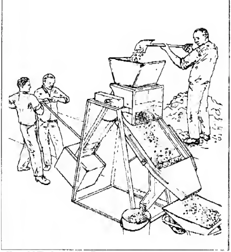


Figure 2.2 The Intermediate Technology Workshop's pendulum crusher.
Source: UNIDO/ILO (1984)

A quite different approach to the problem of reducing energy consumption in brick burning is under investigation at the Housing and Building Research Institute in Bangladesh. The addition of about 5 to 8 per cent phosphoric acid or similar additives to a clay body has been shown to enable phosphate bonds to be formed by firing at temperatures as low as 400! C for only six hours. Strength and density are also higher than for conventional bricks. Phosphoric acid can be manufactured economically as a by-product of phosphate fertilizer production. The investigation is still at a laboratory stage, and the economics of production are not available yet (Haider and others, 1986).

Processing and moulding equipment

While the use of heavy clay soils which are dry when dug is necessary in some areas, these soils need crushing. Crushing with manual tools is laborious, but mechanically powered plant may not be available. The pendulum crusher has been developed by Intermediate Technology Workshops for this situation, (see figure 2.2). The soil is

Equipment manufacturers and suppliers

AUSTRALIA

Automet Industries Pty Ltd
P.O. Box 68
88 Beattie Street
Balmain NSW 2014
General equipment

BELGIUM

Sa Samic
Hanswijvaart 21
2800 Mechelen
General equipment

DENMARK

Niro Atomizer A/S
Gladsaxevej 305
DK-2860 Soeborg
General equipment

FRANCE

CERIC International
18 rue Royale
75008 Paris
General equipment

GHANA

Agricultural Engineers
Accra
Trough mixer

INDIA

Raj Clay Products
5 Mill Officers' Colony
Ashram Road
Navrangpura
Ahmedabad 380009
Semi-mechanized equipment

ITALY

Unimorando Consortium
Corso Don Minzoni 182
14100 Asti
General equipment

KENYA

Christian Industrial Training Centre (CITC)
Meru Road
Pumwani
P.O. Box 72935
Nairobi
Crusher, table mould

NETHERLANDS

Joh's Aberson bv
8120 AA
Olst
Soft mud process moulding equipment

UNITED KINGDOM

Baird and Tatlock Ltd.
Freshwater Road
Chadwell Heath
Essex
General laboratory equipment

British Ceramics Service Co. Ltd.
Bricesco House
Park Avenue
Wolstanton
Newcastle-under-Lyme
Staff ST4 8AT
Kilns

Craven Fawcett Ltd.
P.O. Box 21
Dewsbury Road
Wakefield
Yorkshire WF2 9BD
General equipment

Intermediate Technology Workshops
Overend Road
Cradley Heath
West Midlands B64 7DD
Crusher, table moulds, handling equipment

Kilns and Furnaces Ltd.
Keele Street
Tunstall
Stoke-on-Trent
Staffs ST6 5AS
Kilns

William Boulton Ltd
Providence Engineering Works
Burslem
Stoke on Trent
Staffs ST6 3BQ
General equipment

UNITED STATES OF AMERICA

Interkiln Corporation of America
P.O. Box 2048
Houston
Texas 77252
General equipment

ZIMBABWE

World Radio Systems
Bush House
72-72 Cameron Street
P.O. Box 2772
Harare
Crusher, table moulds

Chapter 3

Soil construction

3.1 Introduction

Soil is used in construction in a huge variety of ways, but this compendium will concentrate on the three predominant methods which have the greatest potential for future development. These are *adobe blocks, pressed-soil blocks,* and *rammed-earth walling.*

Adobe blocks are building blocks formed by making a liquid mixture or slurry of earth and water, which is poured into moulds and then air dried. The blocks may be stabilized or reinforced by the addition of bitumen or chopped fibre. A wide range of scales of production and levels of technology are available. Because of the need for air drying, adobe blocks are most commonly used in arid and semi-arid climates. Their principal use is as a walling material. Generally surface protection is needed to prevent erosion by rain.

Pressed-soil blocks are building blocks or bricks made by compaction of a suitable soil in a mould under pressure. The moulding process can be carried out at a range of scales and levels of technology from simple manual processes to large integrated block production plants producing thousands of blocks per day. The soil may be used unmodified or modified by the addition of a stabilizer such as cement, lime, bitumen or resin. Pressed-soil blocks have the same range of uses in building as bricks and blocks of fired clay or concrete, although surface protection may be more important in the case of unstabilized blocks, or blocks produced by hand-ramming. Pressed soil blocks may be used for roofing and flooring as well as for walling.

Rammed-earth walls are formed in place by compacting earth or soil between temporary forms. The forms are generally of timber, sometimes connected by steel ties. The length and height of forms varies between different methods; lifting and compaction of the soil may be entirely manual, or mechanized. Stabilizers may be used as for pressed blocks. Stabilized walls may need no surface protection, but unstabilized walls usually need to be rendered.

3.2 Raw materials

The raw materials required for soil construction are a suitable soil and a stabilizer where appropriate. This section will summarize available information on the selection of soils and the choice of an appropriate stabilizer.

Soil selection

Three principal properties of a soil are important in judging its suitability for use as a building material. These are its *grading* or *particle size distribution;* its plasticity, or behaviour when mixed with water; and its behaviour under *compaction.* A variety of test methods is available for determining each of these properties. The standard methods require the use of standardized laboratory equipment, and the precise methods are set out in national standards. There are in addition some simplified short-cut methods by which soil types may be classified without the use of standard tests.

The grading of a soil is a measure of the distribution of the sizes of the individual soil particles it contains. Particle size distribution is one of the principal means of assessing whether a soil is suitable for use in construction. Soil particles are divided into four principal size ranges.

Table 3.1. Classification of soils by grain size

Description	Grain size (mm)
Gravel	2.0 to 60
Sand	0.06 to 2.0
Silt	0.002 to 0.06
Clay	Less than 0.002

The proportion of the finer materials (silt and clay) in a soil can be determined by the jar test in which the different proportions of sand (and fine gravel), silt and clay in a soil are approximately determined by the depths of the settlement in the bottom of the jar after shaking and allowing to stand for given periods of time. This test is very simple to carry out but is of rather poor accuracy (Norton, 1986). It is usually important to distinguish more accurately between the silt and clay components of the fine fraction, which can only be done with acceptable accuracy by the combined sedimentation/sieving method (Norton, 1986, or BS 1377 or other national soil testing standards). The results of a grading analysis may be presented in the form of a particle size distribution curve, but for soils which contain no gravel particles the grading is most commonly stated in terms of the proportions by weight of the dry soil falling into the sand, silt and clay sizes. This can be plotted on the triangular chart (see figure 3.1) which is subdivided into 10 different regions, described as sand, silt, clay, sandy clay, loam, clay loam etc. The soils most suitable for soil construction can be identified by their location on this chart (CRATERRE, 1987).

The plasticity of a soil refers to the extent to which a soil will absorb water. The tests for this are carried out only on fine material. The water content by weight at which the soil passes from the rigid to the plastic state (solid but deformable) is called the *plastic limit;* the water content at which the soil passes from the plastic to the liquid state is called the *liquid limit.* The difference between these two water contents is the plasticity index. The standard methods of

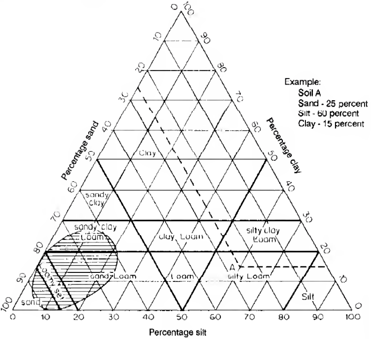


Figure 3.1 Triangular soil classification chart
Source Spence and Cook (1984)

measurement of the liquid and plastic limits are the Atterberg tests. The liquid limit and plasticity index can be plotted on a plasticity chart (see figure 3.2) which, combined with the particle size distribution, offers a good guide to the selection of suitable soils for use in construction.

The compaction properties of a soil are not directly used in soil selection but are needed as a guide to selection of the appropriate water content in pressed-block manufacture and rammed-earth construction. A given amount of compactive effort will produce different densities depending on the amount of water in the soil. At a particular water content, the optimum water content,the density will be maximized. The standard compaction test measures the *optimum water content* and *the maximum dry density*.

The standard tests referred to above are described in national standards such as BS 1377, *Methods of Testing Soils for Civil Engineering Purposes*. A summary of these tests, and of simplified alternative tests which can be used in the field for determination of soil properties or directly for soil selection is given by Norton (1986).

There are different opinions about the soil properties considered appropriate for soil construction, according to the experiences of different users. The type and proportion of stabilizer suggested also vary considerably. There are at present no generally accepted standards. Table 3.2 gives an indication of the ranges of properties and classifications which are likely to be suitable for various uses based on the USCS Geotechnical Classification System. Soils with these properties may not turn out to be suitable, and soils outside these limits are not necessarily unsuitable. Performance tests as described in section 3.4 are a far better guide to the suitability of a soil and should always be carried out. The subject of testing and evaluation is treated extensively by CRATERRE (1987).

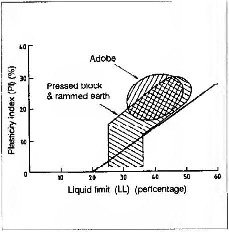


Figure 3.2 Plasticity chart for soil selection
Source CRATERRE (1987)

Stabilizers

The most widely used stabilizers are cement, lime and bitumen. Organic fibrous materials such as chopped straw and cow dung are also sometimes added to adobe blocks. Cement acts principally as a binding agent, forming, after hydration, a rigid skeleton within the soil which increases its strength and reduces its porosity. Cement is best used with cohesionless soils, or soils with a low clay content. Lime is used principally with plastic soils containing relatively large proportions of clay. It acts in two ways: it reduces the plastic and liquid limits of the soil, thus making it more suitable for compaction; and, over a long period, it may also combine with some of the clay minerals in a pozzolanic reaction, which will increase strength and reduce porosity as cement does. In certain circumstances both cement and lime can be used. Bitumen acts as a water repellant, reducing the dimensional changes, loss of strength and surface erosion associated with wetting. It is most successfully used with granular, non-cohesive soils. An alternative to stabilization is to temper or modify an unsuitable soil by the addition of a proportion of another soil. The subject of stabilizers is treated extensively by CRATERRE (1987). The use of bitumen and tempering soil for adobe manufacture is discussed by McHenry (1984).

An indication of the most suitable stabilizer can be obtained by means of the plasticity chart. The choice of stabilizer and the selection of the appropriate stabiliser content is best done by means of trial blocks, with different proportions of the chosen (or alternative) stabilizers. These blocks are then subjected to performance tests such as those for compressive strength, resistance to water erosion and moisture absorption described in section 3.4, and the stabilizer content chosen is the least which repeatedly satisfies all the tests.

3.3 Production technologies

Each of the three principal methods of soil construction involves the following production stages:

(a) Excavation and soil preparation;
(b) Mixing;
(c) Moulding;
(d) Curing.

Soil excavation is normally straightforward. It may be necessary to remove a layer of topsoil or other unsuitable material, or restrict excavation to a particular soil horizon. Manual or mechanized excavation may be used. After excavation the soil will normally need to be dried. This may require storage under cover. Some soils will then need to be pulverized to ensure adequate mixing of the water and stabilizer. Most of the material (except gravel particles) should be reduced to less than 5 mm diameter. Pounding with a rammer followed by screening, hand- operated pulverizers or powered grinders may be used , according to the scale of output.

The other three steps are carried out differently for each of the three methods of soil construction.

3.3.1 Adobe blocks

Mixing

Mixing for adobe production requires the addition of water to soil to bring it to a semi-liquid consistency or paste if the mixture is to be thrown or poured into the moulds, or a plastic consistency if it is to be extruded. Chopped fibre or bitumen emulsion may need to be added. In either case, thorough dispersion of the water and stabiliser throughout the mass of the soil is essential for a good result. The traditional method in many countries is puddling in a soak pit with the feet, or with the assistance of animals, and this can be entirely satisfactory, though highly labour-intensive. The use of a pug-mill, which can be human-powered, animal-powered or motor driven, can greatly reduce the labour. Other types of mixing machines such as linear mixers, concrete mixers and planet-wheel mixers have been used with success (CRATERRE, 1987) where a soft paste is required.

Moulding

Adobe blocks are moulded by throwing or pouring the paste into open-bottomed moulds on the ground. At the smallest scale of production, a single mould is used

Table 3.2. Suitability of soils for soil construction

Soil description	USCS class	General suitability (without stabilization)
Clean gravel, well graded	GW	Not suitable. Fine soil should be added.
Clean gravel poorly graded	GP	Not suitable. Fine soil should be added
Silty gravel	GM	Suitable, but lacks cohesion. Erodes easily. Add fine soil.
Clayey gravel	GC	Suitable. Sometimes fine soil should be added.
Clean sand, well graded	SW	Not suitable. Fine soil should added.
Clean sand, poorly graded	SP	Not suitable. Fine soil should be added.
Silty sand	SM	Suitable, but lacks cohesion. Erodes easily. Add fine soil.
Clayey sand	SC	Suitable. Sometimes fine soil should be added.
Low-plasticity clay	CL	Sometimes suitable. Sandy soil should be added.
Organic silt and clays with low plasticity	OL	Not suitable. Sometimes acceptable.
Highly plastic clay	CH	Rarely suitable. Sandy soil should be added.
Highly plastic silt	MH	Very rarely suitable
Highly plastic organic silt and clay	OH	Not suitable.
Peat and other highly organic soils	PT	Suitable as sod

Source: CRATERRE (1987)

(see figure 3.3). The consistency of the paste is such that the block will retain its shape on demoulding immediately after casting. For larger scales of production, multiple moulds are used. At the largest scale of operation, the paste is poured into large multiple moulds from the bucket of a front-end loader (see figure 3.4). The blocks are then allowed to dry for some time to firm up before the mould is removed. This method requires a substantial investment in moulds, but achieves a much higher productivity. Produced singly, a productivity for a two man team of 500 blocks per day is possible. Productivity can be increased to over 1,000 blocks per day through the use of a mechanical mixer and sufficient gang- moulds for about 500 blocks. With a front-end loader and a larger number of moulds, a three-man team can produce 2,000 or more blocks per day. At the most advanced level of technology, integrated production units are available which can produce in excess of 15,000 blocks per day (McHenry, 1984). Various improved systems are under development (see section 3.6).

Curing

There are two stages to the drying process for adobe blocks. In the first stage, the blocks are left where they have been cast until dry enough to handle. Then they are lifted, turned on their sides and the edges cleaned, and left for a further drying period. They may subsequently be stacked for further drying when sufficient strength has been achieved. The length of these two stages depends on the climate and on the type of soil used. In warm dry climates the initial drying may take from two to three days, and the second stage several weeks. It is essential that the blocks be completely dried before being used. Because of the low tensile stress of adobe blocks, a high wastage rate has to be anticipated in lifting and transport. They are also very vulnerable to any rainfall during the initial drying stage.

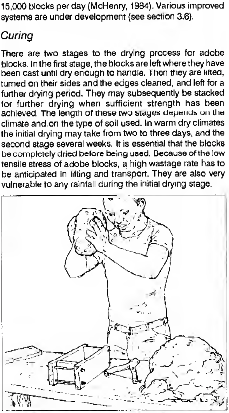


Figure 3.3. Sun-dried block manufacture in single mould
Source. Action-aid, Kenya

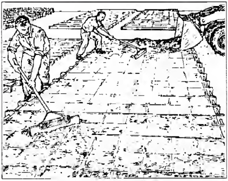


Figure 3.4 Adobe block manufacture - large scale operation
Source: International Foundation for earth construction (IFEC)

3.3.2 Pressed-soil blocks

Mixing

Adequate mixing is vital to the performance of pressed soil blocks. It is carried out in two stages. First the dry ingredients are mixed. These may include soils of different gradings as well as dry stabilizers, lime or cement. The addition of water (containing any liquid stabilizer such as bitumen emulsion) is a separate stage. The water needs to be added gradually. Mixing may be carried out satisfactorily by hand methods, using shovels and watering cans for adding water. For a scale of output exceeding a few hundred blocks per day, mechanized equipment may be more economical. Planet-wheel or paddle-type mixers have been found suitable, but the ordinary drum-type concrete mixer is only suitable for the mixing of dry ingredients owing to the formation of lumps and crumbs. Water should be added during mixing by means of a sprinkler, mist sprayer or (in more elaborate plants) by means of pressurized steam.

Moulding

The simplest method of moulding is by hand-ramming in a wooden or metal mould. The process is almost identical to the hand manufacture of concrete blocks, except that soil replaces the sand and gravel aggregate, the water content is lower, and heavier compaction is used. The process is much more labour- intensive than concrete block manufacture, because of the high compactive effort required. The mould also needs to be stronger to resist the bursting pressures in compaction. Blocks tend to be inadequately compacted and of low strength and durability.

At the next level of technology are the hand presses. These use the lever principle to create a mechanical advantage and thus increase the compaction pressure. They have strong mould boxes, sometimes with several different interchangeable sizes, a ram which applies the compaction pressure, and a means for ejecting the block from the mould after compaction. The most widely available and used is the CINVA ram described by VITA (1975), but there are many variants and imitators, some, but not all, of which are improvements. Hand presses are low-cost, simple to construct and maintain, and easily transported from site to site. The compaction ratio (volume of uncompacted soil to compacted block) is about 1.65, and should not be lower than this. The compaction pressure is about 15 to 20 kg/cm^2, and outputs of around 300 blocks per day or above are normally achieved.

At a higher level of technology, there are a number of motorized presses which have become available relatively recently. The action is similar to the hand presses, but the compaction and ejection of the block is powered by a petrol or electric motor. Some require the mould to be hand-filled for each block, others incorporate a hopper feed mechanism. Pressures are generally a little higher than for manual presses, between 20 to 40 kg/cm^2. Outputs between 400 and 1,500 blocks a day are typical. Costs are substantially higher than for hand presses, energy costs in production are significant, and unreliable performance has been reported from some machines. The output of these presses depends on the production of the previous non-mechanised operations of soil preparation and mixing.

At a still higher level of technology are integrated production units in which part or all of the preparation of the soil is contained within the process. Some of these are mobile production units, which can move from site to site: these have outputs ranging from 2000 to 6000 blocks per day. Others are fixed industrial production units, with outputs up to 30,000 blocks per day. Though they have been used in developing countries, their economic viability is doubtful.

Summaries of the different press types and their characteristics is given by CRATERRE (1987). The subject has also been discussed by Mukerji (1986), and UNIDO/ILO (1987). At present no international standards for moulding equipment are available. Norton (1986) suggests that the compaction ratio should not be less than 1.65, and that a compaction pressure of 10 kg/cm^2 is the bare minimum, and that 20 kg/cm^2 or more is acceptable.

Curing

The appropriate method of curing depends on the stabilizer used. If either cement or lime is used it is essential to keep the blocks moist for a period of at least one week, or two weeks in the case of lime, otherwise the hydration reaction will not be completed, the blocks will lack strength, and the important outer layer will be porous and lack durability. Thus protection from direct sunlight and drying winds is essential. Initially blocks should be laid out on a flat clean surface. After 24 hours they can be stacked. After the wet curing is completed, it is advisable to allow the blocks to dry out so that all shrinkage has taken place before they are built into a wall. This may be omitted if shrinkage will not be a problem. If bitumen has been used as a stabilizer, the blocks can be dried in the open, within four or five days in a hot arid climate, but longer if it is cool or humid.

3.3.3 Rammed-earth walling

Mixing

The soil preparation requirements for rammed-earth walling are exactly the same as for pressed-soil blocks, and the same equipment may be used. Since rammed-earth walls are generally thicker than pressed-block walls, the quantities involved may be larger. Transport and lifting of the mixed soil to fill the moulds is labour-intensive and some mechanization may be beneficial.

Moulding

Formwork for rammed-earth walling is generally made of timber, although other materials have been used. The soil is compacted between an inner and outer leaf, each about 1.5 to 3.0 m long and between 0.5 and 1.0 m high, held at the correct distance apart, and connected by strong ties. The mould or formwork has to be strong enough to withstand the considerable pressures resulting from compaction, and flexible enough to accommodate walls of different thickness and configuration, to be easily dismantled and reassembled for adjacent sections and higher layers of the wall, to form external and internal corners, and to permit the construction of window and door openings. Numerous traditional systems are in use in different countries, and some proprietary and innovative designs are available. The more advanced designs incorporate various devices for speeding dismantling and reassembly (see section 3.6).

Compaction can be carried out either manually or with a powered rammer. Manual rammers or tampers consist of a rod about 1.5 m long with a heavy head of steel or wood, the whole tool weighing between 7 and 10 kg. Powered tampers of the impact type are suitable. These are driven by air compressors. The rate of compaction is increased, but the equipment is expensive and suitable only for high volume production. With manual compaction in moulds of standard size, a team of three or four can build about 3 to 4 m3 per day. With larger moulds and mechanical compaction, the same sized team can build up to 20 m^3 per day.

Curing

Curing or drying of a rammed-earth wall should be slow to avoid cracking. The walls should be sprayed with water, or wrapped in plastic or covered with grass screens to prevent rapid drying.

Details of different types of formwork and methods for rammed- earth walling are given by CRATERRE (1987), McHenry (1984), Easton (1982), and Norton (1986).

3.4 Performance standards

Few countries have formulated specific standards for soil construction. Among those that have are India (IS:1725-1960, and IS:2110-1962, for soil-cement blocks and rammed-earth walls) and Peru (ITINTEC 331.201/202/203-1978 for adobe walls). Various manuals have proposed standards for particular tests and there is general agreement about some of the basic properties which should be considered. Standards are discussed by CRATERRE (1987), UNIDO/ILO (1987), Norton (1986),and McHenry (1984).

For all types of soil construction, the important properties to be considered in formulating standards are *compressive strength, water absorption and weather resistance*. For brick and block manufacture, dimensional accuracy should also be specified.

The *water absorption test* is to measure the porosity of a masonry unit. Porous building blocks will allow water to penetrate the wall, will tend to expand and shrink seasonally, and have reduced durability. It is especially important to prevent water absorption in soil construction where there is a significant clay content. The water absorption of an individual block is most accurately measured by oven-drying the block for 24 hours and then weighing it; the block is then immersed in water for a further 24 hours and re-weighed. The water absorption is the difference in weight expressed as a percentage of the dry weight, averaged over a sample of five blocks. An upper limit of 15 per cent has been proposed, but a well-stabilized block should have a water absorption not exceeding 10 per cent. If an oven is unavailable, water absorption may be calculated by comparison with the air-dried state. In this case the limit should be lower; Norton(1986) has suggested a limit of 4 per cent.

A *compressive strength test* is required in order to ensure that a soil wall is able to sustain its load without failure or local crushing at points of high stress. Compressive strength is normally an indication of durability also. The compressive strength of soil blocks is measured in the laboratory by a compression testing machine of the type used for testing concrete. If a stabilizer is used, it is normal to carry out the test at an age of 28 days. The block is immersed in water for 48 hours before testing. The highest stress reached is recorded, averaged over a sample of five blocks. Norton (1986) and UNIDO/ILO (1987) give details of simplified compression testing devices which can be constructed in the field away from a testing laboratory. These are unable to provide a load large enough to fail a full-sized block, so a smaller sample has to be used. They are, therefore, not very accurate. For use in single- or two-storey buildings, minimum strengths between 10 and 20 kg/cm2 are proposed. If the wall is to be protected from water or used in an arid climate, a measure of the dry strength may be more appropriate. A minimum of 21 kg/cm2 has been proposed.

The weathering resistance of a pressed soil block may be measured by a *water spray test*, or by the more severe *abrasion test*. In areas which are subjected to frost, a *freeze-thaw test* might also be needed. In the water spray test, the block is subjected to a specified water spray under pressure for a period of two hours. The block is then inspected for any sign of deterioration (UNIDO/ILO,1987). In the abrasion test, a block is subjected to 12 cycles of wetting and drying for specified periods, followed by wire brushing to remove loose material. The weight loss is then determined. A maximum of 10 per cent weight loss based on the initial oven-dry weight has been suggested, but this test is unduly severe for many climates and uses of soil.

For rammed-earth walling these tests may be carried out either on a sample cut from a completed section of wall, or on a specially made test block, which is compacted to the same density as the wall.

Other tests which have been used include:

(a) *Modulus of rupture test:* a block is supported at its ends and subjected to a point load at the midpoint until failure occurs. For stabilized soil blocks a minimum average tensile stress of 2 kg/cm2 based on three blocks has been proposed. The test is not appropriate to unstabilized adobe, which will have a much lower tensile strength;

(b) *Specific density test:* the dry and wet densities of blocks and samples are measured. Minimum values of 1700 kg/cm2 and 1870 kg/cm2 for the dry and wet states for stabilized soil blocks have been proposed (CRATERRE, 1987);

(c) *Surface appearance*: various limitations on edge and surface appearance and dimensional variations have been suggested (CRATERRE, 1987, UNIDO/ILO, 1987).

3.5 Uses in construction

Adobe blocks

Adobe blocks are commonly of larger plan dimensions than pressed-soil blocks. A length of 350 to 400 mm is common with a width just under half the length. Walls built with adobe blocks have a thickness of at least one block length, and are laid with alternate courses of headers and stretchers, with the vertical joints overlapped. The mortar used in construction is normally the same soil as is used for making the bricks. The foundation needs careful consideration as it must protect the base of the wall from water-erosion and distribute the load to the ground evenly to prevent differential settlement. The top of the wall will generally support a wall-plate, bond beam or ring beam on to which roof loads will be transmitted. The design of the ring beam is particularly important in earthquake areas. Design aspects are covered by Norton (1986), CRATERRE (1987) and McHenry (1984). Adobe walls will normally be protected by a surface render. Renders are discussed below.

Pressed-soil blocks

Pressed-soil blocks can be used in a similar way to other masonry materials such as concrete blocks and burnt-clay bricks. Dimensions vary, but a plan size of 290 by 140 mm is common to a number of machines, with a thickness of 90 mm. The standard wall thickness is equal to the brick length, but for small houses in climates without temperature extremes, a single leaf wall can be used. Mortars may be of soil or soil-cement, or any of the standard mixtures (see section 4.5.2). It is important that the mortar should not be stronger than the blocks, otherwise cracking will occur, for this reason lime or lime-pozzolana mortars are preferable to cement-based mortars. If the blocks are well stabilized, it may not be necessary to render them; but unstabilized blocks should always be protected by a render of one of the types mentioned below.

Rammed-earth walling

The thickness of a rammed-earth wall depends on both the soil and the climate and is usually determined by local tradition. Thicknesses varying from 300 mm to 500 mm are common. Shrinkage during drying can be a common problem, which can lead to vertical cracking and structural instability, particularly if the soil has a substantial amount of clay in it. For this reason the sections of wall in successive layers are often built in such a way as to stagger the vertical joints. Asymmetrical corner formwork is one device used to achieve this. Foundations and ring beams need to be dealt with as for adobe walls. These design matters are discussed by CRATERRE (1987), Norton (1986) and McHenry (1984). Rendering will normally be required, and is discussed below.

Renders

Renders for soil walls need to be carefully considered to ensure adhesion and limit subsequent cracking, spalling and disintegration. Cement-based renders are too brittle for most situations and do not adhere well. For well-stabilized walls of pressed blocks or rammed earth, a cement-based render may be used if a sufficient period of curing and drying has been allowed. External renders based on cement, lime and pozzolanas are discussed in section 4.5.2. In most other situations an earth- based render is preferable. The durability of earth plasters can be improved by the addition of fibrous material such as cowdung or animal hair, or by the use of bitumen, or the addition of lime. The preparation of the wall for the application of a render by adding a key of wooden pegs, broken tiles or projecting fibres will improve adhesion of these renders. Other surface treatments are painting with thin lime or cement slurries, protection with matting or facing with a more durable material. There are also numerous traditional local renders for earth walls based on local plants or animal products. Some interesting innovations in the rendering of earth walls are discussed in section 3.6. In general, renders for earth walls can be expected to require some maintenance and repair, particularly in climates with a high rainfall. The subject of renders for earth walls is discussed by Norton (1986), CRATERRE (1987), and McHenry (1984). Traditional renders are described by Schreckenbach and Abankwa (1984).

3.6 Innovations in soil-construction technology

In recent years there has been an enormous upsurge of interest in soil-construction technology worldwide. Research institutes have undertaken projects, and development agencies have been particularly effective in implementing application projects. Manufacturers have followed with a wide range of new equipment, much of it unproven. The manufacture of pressed-soil blocks has been a subject particularly rich in innovation, and there have been advances in adobe blocks, rammed-earth walling and other aspects of soil-construction technology.

Adobe blocks

A comprehensive study of the manufacture of adobe blocks has been made by the International Institute of Housing Technology at Fresno, California, leading to procedures for stabilizing with bitumen (or asphalt). This is the established practice in adobe brick manufacture in the south-western United States. Developments in adobe manufacture have been largely in the organization of production to improve output. The Hans Sumpf Company of Fresno has developed an integrated production process, with a loader-conveyor to load a screw-type pug-mill continuously; the output of this is transported to a self-propelled moulding machine which moves along a line of moulds on the ground, filling and screeding them. The operation is capable of producing 15,000 to 20,000 blocks per day.

In other countries, bitumen is not easily available for stabilization, especially in rural areas, and studies of other materials have been made. At Istanbul Technical University it has been shown that the addition of 10 per cent semi-hydrate gypsum plaster improves the compressive and flexural strength by a factor of 2 or 3, and reduces shrinkage by a factor of 3 or 4, while also reducing demoulding and curing times. Some demonstration houses have been built for long-term durability testing (Kafescioglu and others, 1983). Research at Middle East Technical University into the properties of soils and stabilizers used in Turkey including straw has led to the establishment of soil selection procedures and a standard Code of Practice for adobe block manufacture (Erdogan,1987, and Turkish Standards Institute,1977).

Procedures for manufacturing sun-dried earth bricks have been developed by Action-Aid, Kenya, which involve the use of a mortar reinforced with cowdung. A manual describing the process has been published (Action Aid, undated).

Pressed soil blocks

One fruitful field of research has been to extend the range of soils which can be effectively stabilized using manual block presses and economical stabilizer contents. In India, the Structural Engineering Research Centre at Madras has developed a process for stabilization of laterite with lime, by means of a period of curing at temperatures of around 100° C. The blocks are said to have wet compressive strengths between 50 and 150 kg/cm^2, water absorption around 12 per cent, and very good accuracy of moulding and dimensional stability (Subrahmanyam and others, 1983). Lateritic soils have also been investigated in Nigeria (Akinmusuru, 1984), the United Republic of Tanzania and in Zambia (Spence, 1971). In Kenya, the most effective way to stabilize a wide range of soil types was investigated, including murram and black cotton soils (Kateregga, 1983). This work demonstrated that, using the BREPAK block press, a mixture of 70 per cent black cotton soil with 25 per cent sand and 5 per cent lime could be used to produce well-stabilized blocks. In Mayotte, a mixture of 30 per cent local earth and 70 per cent laterite is stabilized with 9 per cent cement in a well established block production process which had produced 3.5 million blocks by 1985 (CSTB,1986). The Building Research Institute, Jamaica, has shown that bauxite waste or red mud can be successfully stabilized with the addition of 7 per cent cement (Building Research Institute, 1985). Fibre reinforcement for stabilized soil blocks has been investigated in Nigeria (Kinmusuru,1981), and the use of rice- husk ash as a stabilizer has been investigated by the Housing and Building Research Institute in Bangladesh. CITADOB, a Belgian company, has developed a waterproofing additive, which can replace cement as a stabilizer, with a claimed improvement in water resistance. The process is known as STABIADOB.

The development of blockmaking machinery has been very rapid in recent years. Several reviews have been published (Mukerji 1986; UNIDO/ILO,1987; CRATERRE, 1987). The principal aims of these developments have been to improve compaction pressure or to increase productivity or both, without losing the essential characteristics of robustness and portability. Many of the manual presses are developments of the CINVA ram. The Tek-block press developed at the University of Science and Technology in Ghana has a compaction pressure of 15 kg/cm^2, and produces blocks of dimensions 290 mm by 215 mm by 140 mm; a production rate of 175 blocks a day is achieved by a five-man team. The Astram press developed by the Centre for the Application of Science and Technology to Rural Areas (ASTRA) in India, has a compaction pressure of 50 kg/cm^2, and produces blocks of dimensions 300 mm by 145 mm by 100 mm or 300 by 230 by 100 mm. The CETA-ram, developed by the University of San Carlos, Guatemala, produces perforated blocks of overall dimensions 320 mm by 152 mm by 110 mm with two 60 mm diameter holes passing through the thickness of the blocks. Hollow blocks are also produced by the CITADOB PTC-1 press.

The BREPAK (see figure 3.5), developed by the United Kingdom Building Research Establishment, uses a

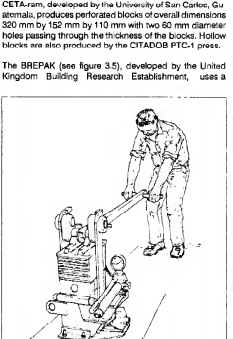


Figure 3.5 The BREPAK soil block press

hydraulically-assisted manually-operated lever to achieve a much greater compaction pressure of 100 kg/cm^2. This can achieve high-quality blocks with limited stabilizer contents, but at the expense of a somewhat lower rate of production (UNIDO/ILO, 1987).

The CRATERRE press (see figure 3.6), developed in Peru in conjunction with ININTEC, has a compaction pressure of 15 to 20 kg/cm^2; the blocks have dimensions of 280 by 280 by 80 mm, with or without indentations to assist bonding, a size similar to traditional adobes. A production rate of 120 blocks per hour is claimed.

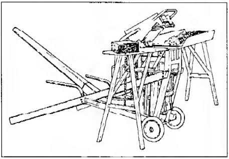


Figure 3.6. The CRATERRE soil block press

Another development has been the appearance of numerous commercially produced power-assisted block presses for increased levels of productivity. The claimed production rate and cost of some of these is given in by CRATERRE (1987). They have warned, however, that some of the machines on the market have not been subject to very extensive field testing, and have proved unreliable in practice.

A further interesting innovation has been in industrial processes to produce stabilized soil blocks on a large scale. The Latorex process developed by Drostholm Products, and the Latoblock process developed by the Structural Engineering Research Centre, Madras both use lime stabilization of lateritic soils in conjunction with a high temperature curing regime. Precise details of the processes are unavailable but a very low energy input per block is claimed. The two processes produce blocks at a level of 12,000 and 5,000 blocks per eight-hour day respectively. Equipment for large-scale block production is also marketed by Torsa Maquinas y Equipamentos of Sao Paulo (Supertor) and Equipamentos Meccanicos Ltda of Brazil (Tecmor). A range of scales of production and different sizes of product, including roof tiles, can be produced.

At the other end of the scale, there have been projects in which stabilized soil blocks have been made without the use of a block press, using manual compaction only. The process is well- established in squatter upgrading schemes in Zambia, where it was pioneered by the American Friends Service Committee after earlier experimentation with the CINVA ram (CRATERRE, 1987). A soil- cement mixture is compacted in a steel block mould similar to those used for concrete block-making (see figure 3.7). The compaction of the blocks produced this way is often very poor, but it is a process suitable for the self-help builder. A similar process, using wooden moulds, has been pioneered by Action-Aid for use in rural building projects in Kenya and Senegal.

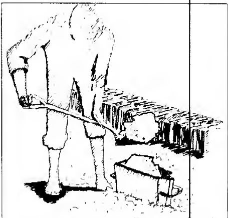


Figure 3.7. Stabilized soil block manufacture- hand ramming
Source: Spence and cook (1984)

Manuals on stabilized soil block-making have been published by VITA, ITDG, Action-Aid, the Commission for Technical and Vocational Training, Zambia and the International Foundation for Earthen Construction.

Rammed-earth walling

Innovations in rammed earth walling technology have been principally concerned with the design of the formwork. Traditional systems, though simple to construct, are small, and output is slow because of the need to move them frequently.

An early innovation in shuttering was the rolling formwork developed at CSIRO in Australia by G.F. Middleton (see figure 3.8). Tall struts extending beyond the form eliminate the need for through bolting at the bottom of the form, rollers at each end enable the formwork to be shifted rapidly into place for the next section of walling (Middleton, 1975).

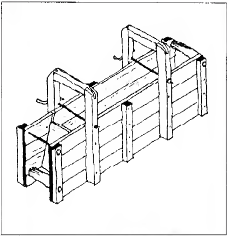


Figure 3.8. Rammed-earth construction - the rolling mould
Source: Middletown (1975)

Formwork suitable for easy construction, assembly and dismantling and for volume production has been developed by the Earth Resources Technology Center in the United States, (see figure 3.9). It uses plywood sheets, walings from standard softwood timber sections, and small diameter steel pipe and standard furniture clamps or "pony clamps" for connections. The formwork extends the full height of a single-storey wall, divided vertically into two 1.2 m lifts, and has a length of 1.2 m. This enables a complete door frame assembly to be incorporated within a single mould. The moulds are strong enough for heavy mechanical tamping to be used, and allow production at a rate of 20 tons per day.

CRATERRE, Peru, has developed a formwork system based on observation of the traditional Andean earth-builders. Its side panels have dimensions of 1.8 m long by 0.55 m high, which are connected by 25 mm dia. through bolts secured by wing-nuts. It has been used in numerous community projects (CRATERRE, 1984) (see figure 3.8).

The agencies, Centro Sinchaguasin and Funhabit, in rural Ecuador have developed a modified traditional formwork system for use in reconstruction after the March 1987 earthquake. It was noticed by the survivors that a weakness of the traditional rammed-earth wall was that it permitted a vertical crack to develop at the corners, allowing separation and overturning of the walls. A modified asymmetrical corner formwork was designed (see figure 3.11) which enables the corner joint to be staggered and improves the corner bonding between walls. This can be made by local craftsmen. The internal corner is chamfered to reduce the stress concentration and other improvements are incorporated.

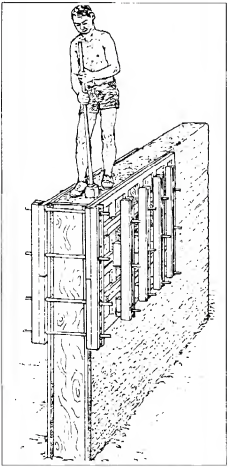


Figure 3.9. Rammed-earth construction - the rapid assembly mould

Other developments

There have been a number of innovations concerning methods for the protection of earth walls. The Central

Building Research Institute at Roorkee in India has developed a waterproof plaster. A mixture of soil and straw is first prepared, then mixed with water and left to soak.

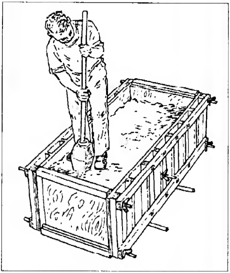


Figure 3.10. Rammed-earth construction- the CRATERRE mould

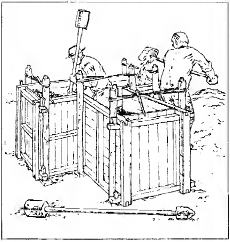


Figure 3.11. Rammed-earth construction - Ecuador mould
Source: Centro Sinchaguasin

A 5 per cent addition of bitumen cut-back (80/100 grade bitumen mixed with kerosene oil and paraffin wax in ratio 100:20:1) is mixed with the plaster just before using it (Mathur, 1987). A number of innovative treatments are described by Norton (1986), including the use of thin fired-clay tiles as a facing layer. The tiles are inserted into the mould before the bricks are moulded. They incorporate lugs to form a bond between the two materials (GRET, 1985). Centro Sinchaguasin in Ecuador has developed a lime-wash render suitable for rammed-earth walls by blending in a small proportion of PVA woodworking glue, and a technique for protecting the tops of free-standing walls with a stabilized soil coping (see figure 3.12).

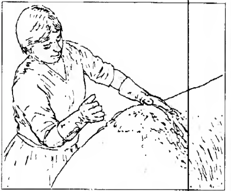


Figure 3.12 Earthen-wall protection in Ecuador
Source: Centro Sinchaguasin

The Development Workshop has developed a method for improving the earthquake resistance of earth walls for reconstruction after the 1983 earthquake in north-west Guinea. The walls were built in the traditional way, but reinforced externally and internally with a lattice of vertical and horizontal bamboos after plastering (see figure 3.13). The reason for using external reinforcement is that rotting is inevitable. If the bamboos are left visible, they can easily be checked and replaced when needed. (Norton, 1987)

At the Asian Institute of Technology, Bangkok, Professor Bruce Etherington has developed the LOK-BILD soil block construction system (see figure 3.14). The system consists of interlocking dry-laid concrete or soil-cement blocks with precast-concrete floor joists which interlock into the walls. The system combines ease of fabrication with good strength and durability. It has been demonstrated in projects in Malaysia, the Philippines and Thailand (Etherington, 1987).

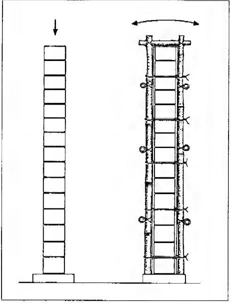


Figure 3.13. Strengthening earthen walls to resist earthquakes
Source: Norton (1987)

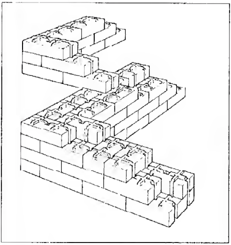


Figure 3.14. The LOK-BILD soil-block construction system

PARAGUAY

CTA
Facultad de Ciencias y Tecnologia
Universidad Catolica
Asuncion
CTA block press

PERU

CRATerre Perou
Apartado Postal 399
Huancayo
CRATerre Perou block press

SWITZERLAND

Consolid AG
Aechelistrasse 18
CH-9435 Heerbrugg SG
CLU 3000 powered integrated block press

ETH-Honggerberg
Institut für Hochbautechnik
8093 Zurich
Saturnia

Meili Engineering
Gewerbe Centre Rothaus
CH-8635 Durnten
MEILI-60 manual block press

Maro Enterprise
95/B route de Suisse
Maro manual block press
D.Schmidheini
Berg
CH-9436 Balgach SG
ECOBRICK 1000 mobile block production unit

UNITED KINGDOM

Welding Industries Ltd
Blackswarth Road
Bristol BS5 8AX
BREPAK Multiblok

ZORA Company Ltd
112 Power Road
London W4 5PY
ZORA powered block press

UNITED STATES OF AMERICA

Earth Technology Corporation
175 Drennen Road
Orlando, FL 32806
TERRABLOCK Duplex

Hans Sumpf Adobe Co
Fresno
California
via IFEC
3282 Theresa Lane
Lafayette CA 94549
Hans Sumpf adobe process

ULTRABLOC
P.O. Box 1363
Corrales, NM 87048
Ultrabloc

Chapter 4

Low-cost binders

4.1 Introduction

The term low-cost binders refers to materials other than Portland cement, which have cementitious properties (that is to say, they have the property of binding concretes, mortars etc), and which in certain circumstances can be produced and made available more cheaply. These materials have in common the use of simple processing technologies (compared with Portland cement production), and in many cases the potential for lower energy consumption; in addition, they make use of widely available raw materials. This compendium will deal with four types of low-cost binding materials: lime, lime-pozzolana mixtures, blended cements, and gypsum plaster.

4.1.1 Lime

Lime is a material derived from limestone or other forms of calcium or magnesium carbonate. For building purposes it is normally purchased in the form of a fine powder, dry hydrated lime, though it is also sometimes sold mixed with water in the plastic state as lime putty. Its uses in building are as a binder in mortar, usually though not always in combination with Portland cement or pozzolanas, for sand-lime brick production, for soil stabilization, and for plasters, renders and washes.

Lime has many non-building uses, notably in the chemical, metallurgical and food industries, in water and waste treatment, and in agriculture. Lime is manufactured from limestone by burning the raw material in a lime kiln to produce quicklime. Quicklime is then slaked or hydrated by the addition of water to produce hydrated lime.

4.1.2 Pozzolanas and blended cements

Pozzolanas are siliceous materials which on their own have little or no binding property, but when mixed with lime in the presence of water, will set and harden like cement. The most commonly used pozzolanas are volcanic ash (or trass), - a naturally occurring pozzolana; fly ash, rice-husk ash, and calcined clay (or surkhi), all artificial pozzolanas. Other materials such as bauxite waste, diatomite, and opaline chert have been found in the laboratory to have pozzolanic properties, but have been little exploited in practice. Pozzolanas are used in two ways. They can be used in lime-pozzolana mixtures, substituting for cement in a wide range of building applications, including mortars and plasters (for which their properties are particularly suitable), block making and low-strength concretes.

Pozzolanas can also be used to make blended cements, by intergrinding them with Portland cement clinker in suitable proportions. The resulting Portland-pozzolana cements have a range of properties according to the type of pozzolana, the proportions used and the processing employed. At best, they can achieve in every respect the physical properties of Portland cements. Some other materials, also referred to as blended cements, are manufactured by blending or intergrinding Portland cement powder or clinker with inert materials such as limestone. These materials, properly referred to as masonry cements, are manufactured primarily for use in mortars and renders for masonry work, and have a lower strength and rate of strength development than Portland-pozzolana cements.

4.1.3 Gypsum

Gypsum plaster is a traditional product made from heating mineral gypsum, (which can be from natural or by-product sources), which is used as a wall and decorative render for buildings, and as a binding material to make mortars and concrete.

Heating raw gypsum causes a chemical reaction in the gypsum which changes it from hydrous calcium sulphate, to calcium hemi- hydrate. This process is known as calcining and the resulting hemi-hydrate is gypsum plaster. The chemical change is reversed simply by adding water. The hemi-hydrate reverts to hydrous calcium sulphate and sets by re-establishing a crystalline matrix, which forms the bonding power of gypsum.

4.2 Raw materials

4.2.1 Lime

Limestone suitable for lime-burning occurs in a wide variety of forms. The most common is consolidated sedimentary limestone, but in certain circumstances other forms can be used. These include sea shells and coral, chemically precipitated limestones such as travertine, and marble. Dolomite and dolomitic limestones can be used if special attention is given to hydration. Argillaceous limestones can be used to manufacture a hydraulic lime which is ideal for use in mortars and plasters, but unsuitable for some other uses.

The suitability of a limestone as a raw material for lime-burning depends on its chemical composition and its physical properties. A high proportion (i.e. more than 90 per cent) of calcium carbonate is desirable for most uses but is not necessary if the lime is to be used only for mortars and plasters. A proportion of magnesium carbonate is acceptable if autoclave hydration is to be used. Other impurities such as silica, iron-bearing minerals, carbon, phosphate and sulphur can be tolerated within certain limits.

For most small-scale kilns, the physical nature of the stone needs to be such that it will break into lumps of roughly equal dimensions when being prepared for the kiln and will remain as lumps until it leaves the kiln as quicklime. To achieve this, the raw material needs to be a fairly hard limestone that resists abrasion, has uniform porosity, is massively bedded and jointed rather than flaky, and is able to withstand rapid temperature changes without breaking into small pieces (decrepitating).

The assessment of raw materials for lime-burning is a matter for a specialist geologist. National geological survey departments normally have experience, and because of the importance of limestone as a raw material for industry and building, preliminary surveys of many deposits may have already been carried out. The geologist will need to know the expected scale of output over a number of years and any limitations on the location of the kiln. Small-scale burning trials should always be done in addition to laboratory investigations to test the performance of the stone under firing conditions. Raw materials assessment is discussed in detail by Hill in Wingate (1985).

4.2.2 Calcined-clay pozzolana

The raw material required for calcined-clay pozzolana is a suitable clay. Since the initial processes for the manufacture of burnt clay bricks and clay pozzolana are identical (and clay pozzolana was traditionally derived from pulverizing bricks and tiles), brick- and tilemaking clays are often suitable. The chemical composition (on an oven-dry basis) of some clays which have been found suitable in India conform to the requirements shown in table 4.1.

Table 4.1. Chemical composition of some clays suitable for use in calcined clay pozzolana

Constituents	Contents by weight
Silica + Alumina + Iron oxide $SiO_2 + Al_2O_3 + Fe_2O_3$	Not less than 70 per cent
Silica (SiO_2)	Not more than 40 per cent
Calcium oxide (CaO)	Not more than 10 per cent
Magnesium oxide (MgO)	Not more than 3 per cent
Sulphur trioxide (SO_3)	Not more than 3 per cent
Water-soluble alkali	Not more than 0.1 per cent
Water soluble material	Not more than 1 per cent
Loss on ignition	Not more than 10 per cent

Source. IS:1344-1981

Raw materials for calcined clay pozzolana should also be free from coarse sand or gravel, greater than about 0.60

4.2.3 Fly-ash pozzolana

Fly ash is a finely divided residue resulting from the combustion of ground or powdered bituminous coal or lignite, which has been extracted (by cyclone separator or electrostatic precipitation) from the flue gases of boilers fired by these fuels. It is generally obtained as a waste material from thermal power stations or other industrial plants. Bottom ash from boilers is not suitable. Standards require certain chemical and physical requirements. Indian Standard IS: 3812-1981 specifies the chemical requirements shown in table 4.2.

Table 4.2. Chemical composition requirement for fly-ash pozzolana

Constituents	Contents by weight
Silica + Alumina + Iron oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$)	Not less than 70 per cent
Silica (SiO_2)	Not less than 35 per cent
Magnesium oxide (MgO)	Not more than 5 per cent
Sulphur trioxide (SO_3)	Not more than 2.75 per cent
Available alkali	Not more than 1.5 per cent
Loss on ignition	Not more than 12 per cent

Source. IS:3812-1981

4.2.4 Rice-husk ash pozzolana

The use of rice-husk ash as a pozzolana is a relatively new development, and to date no formally approved standard exists. Rice-husk ash is derived from rice husks, a waste material obtainable at rice mills. One process makes use of rice husk ash obtained from burning rice husk as fuel in the production of parboiled paddy. This leads to an ash of variable quality. More recently developed processes have used specially designed incinerators for burning ash. The quality of the ash is improved, but the energy of burning is lost. The ash of fully burned rice husk is over 90 per cent silica. The ash from burning other agricultural wastes such as rice straw and bagasse is also suitable, though the percentages of silica in the ash and the ash content tends to be lower than for rice husk ash.

4.2.5 Volcanic-ash pozzolana

A wide variety of volcanic materials have been used as pozzolanas. Physical and chemical requirements depend on the processing and end use proposed and no generally agreed standards exist. Volcanic-ash pozzolanas usually have chemical compositions within the limits shown in table 4.3 (Spence and Cook, 1984).

Table 4.3. Typcal chemical composition of volcanic pozzolanas

Constituents	Contents by weight
Silica (SiO_2)	45-65 per cent
Alumina + Iron oxide (Al_2O_3 + Fe_2O_3)	15-30 per cent
CaO + MgO + alkalis	15 per cent
Loss on ignition	Up to 12 per cent

Their physical condition may range from loose fine material to coarse deposits containing large dopen-textured pyroclasts and glassy fragments. Deposits may be loose or cemented. Often transportation by water after deposition will have sorted the ash by size to some extent, which will make extensive exploration to find the most active or easily worked material worthwhile (Allen and Spence, 1983).

4.2.6 Gypsum

Hydrous calcium sulphate, CaSO4.2H2O, the raw material used to make gypsum is a calcium-based mineral which is found naturally of a number of forms:

(a) The most common is rock gypsum, which is found in sedimentary rock formations. It is usually white and opaque but can be found in a very finely grained and translucent form, famous as alabaster. Most rock gypsum deposits are relatively narrow seams and occur close to or on the surface (gypsum is chemically altered at depth), allowing exploitation with conventional shallow quarrying techniques:

(i) Open-cast mines where gypsum is cut down in benches, leaving a stepped profile to the quarry to allow progressive exploitation at a number of levels;

(ii) Drift mines where sloping access tunnels allow vehicles to be driven or drawn from the surface down to underground workings. Subterranean galleries are exploited in pillar-and- stall configurations leaving columns of rock gypsum standing to support the roof;

(iii) Subterranean galleries can be dug from pits or shallow shafts sunk down to the level of the deposit. The rock gypsum is winched to the surface.

In mechanized extraction, the rock is excavated by explosive blasting and scooping with a mechanical digger. However, gypsum rock is relatively soft, especially when underground and with a high moisture content, and for centuries before mechanized extraction it was cut by hand with a pickaxe. Manual extraction gives much more regularly shaped and more homogeneous sizes of blocks than does mechanical extraction, which may require further breaking up before the rock is crushed.

(b) The second most common source of mined gypsum is gypsum sand, also known as seed gypsum, which consists of beds or sand dunes of wind-blown deposits. This is easily dug with mechanical diggers or manually with spades. Gypsum sand therefore forms a readily accessible source of material for small-scale operations with limited machinery. One of the problems of gypsum sand is that it is rarely as pure as rock gypsum, often being mixed with other wind-blown minerals. In some cases it may require special processing to decontaminate it for use as a building material.

(c) Gypsite is a very fine form of gypsum sand usually found overlying deposits of it. Gypsite is commonly dug to excavate the gypsum sand below it. It is usually found mixed with topsoil and other contaminants and may contain as little as 60 per cent gypsum. Because of this degree of impurity it is normally not used as building material but is used for agriculture, as a soil additive.

(d) Smaller deposits of gypsum can be found as fibrous gypsum, also known as satin spar, or as crystalline gypsum, also known as selenite. Fibrous gypsum is found in thin seams or within larger deposits of rock gypsum. Crystalline gypsum is occasionally found in large, foliated sheets. It is usually translucent or transparent, leading to its use as window glass in traditional buildings.

There is also considerable interest in obtaining building-quality gypsum as a waste-product material. Gypsum is produced as a by- product of the manufacture of phosphate fertilizer, in the production of salt, to produce phospho-gypsum, and in the cleaning process of desulphurizing exhaust fumes from power stations, during which quantities of mined limestone are converted into sulphur-gypsum. Waste product gypsum is often offered for sale to the building industry at extremely favourable prices. Some by-product gypsum contains impurities which may need expensive decontamination or neutralizing before it can be used in building.

4.3 Production technologies

4.3.1 Lime

The three essential aspects of the production technology are:

(a) Quarrying and stone preparation;
(b) Burning (or firing);
(c) Hydration.

Quarrying and stone preparation

Preparation of the stone for a lime kiln involves quarrying or extracting operations, transporting to the kiln, eliminating undersized and oversized material and removing contaminating materials. The methods used depend on the nature of the stone, the scale of operation and the type of kiln to be used. Simple hand tools may be appropriate for very small scales of operation, but controlled blasting and the use of mechanical diggers and trucks, and screening, crushing and washing equipment becomes economical even for quite small levels of continuous output (e.g. 5 tons/day). The methods are identical to small-scale quarrying methods used in other extractive industries.

Lime-burning

Lime burning takes place in a lime kiln. In the kiln limestone is heated to a temperature at which dissociation takes place. The calcium (and magnesium) carbonates are gradually converted to calcium and magnesium oxide, and carbon dioxide is removed. The temperature required for calcination depends on the type of stone. Kiln temperatures are normally between 900°C and 1250°C. The stone must remain at this temperature long enough for the whole stone to be dissociated. If the dwell time is too short, or the temperature is too low, the stone will be underburned and contain a core of calcium or magnesium carbonate. If the temperature is too high, the lime is overburned and is difficult to slake.

Many types of lime kilns are in use, ranging from primitive field kilns which are built to fire a few tons of lime at a time, to large highly automated continuous kilns with daily outputs exceeding 500 tons.

Lime kilns may be classified according to the following types:

(a) Batch or intermittent kilns;
(b) Vertical shaft kilns;
(c) Rotary and other kilns.

Only the first two types are of importance to this compendium, since rotary and other kilns are large-scale manufacturing enterprises.

In a batch kiln, each kiln load is fired separately. The stone is placed manually within the kiln. A fire is created to burn fuel below and within the stone until all the stone has been converted to quicklime. The quicklime is then allowed to cool and is removed. Sometimes no permanent kiln walls are built and the stone and fuel are simply piled on the ground. Such kilns are very common in rural areas. Their great advantages are their very low capital cost and seasonal production. They are very inefficient in their use of fuel and a high proportion of underburned and some overburned lime is invariably produced leading to a poor quality lime. The simpler kilns have been described in detail by Wingate (1985).

In vertical shaft kilns, the stone falls slowly under gravity through a cylindrical shaft in which it is preheated, burned and then cooled before finally being discharged at the base. Feeding of the stone at the top and discharge at the bottom are continuous. Fuel is fed so as to maintain a constant temperature in the firing zone. Air for combustion is drawn in through the base and warmed by the cooling stone, while the hot exhaust gases are discharged at the top of the kiln warming the incoming stone. Most of the heat used to raise the temperature of the stone and air is recovered and this results in much lower fuel consumption than for batch kilns. Mixed feed kilns use coal, coke or firewood or even peat as fuel. The fuel is fed in at the top of the kiln in alternating layers with the stone, or is premixed with it. Oil or gas-fired shaft kilns are also available. In these the oil or gas burners are located in the firing zone. As they produce no ash the quicklime is cleaner than for mixed feed kilns, but it is difficult to design a system which maintains a constant temperature, so more sophisticated controls are required. There is a great variety of kiln designs available, suitable for different fuels, types of stone and scales of output. UNIDO (1987) gives a good summary. A small-scale example, suitable for an output level of 3 to 5 tons per day, designed by the Indian Khadi and Village Industries Commission, is illustrated in figure 4.1.

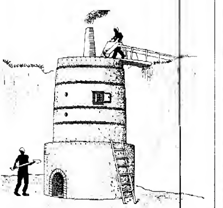


Figure 4.1. The Khadi and Village Industries Commission (KVIC) improved shaft kiln

A few examples of recent innovative small-scale kiln designs are described in section 4.6.

Hydration

Hydration is the addition of water to quicklime, the lumps of burned lime which are discharged from the kiln, to cause it to expand and disintegrate into very fine particles. This occurs through a chemical reaction between the water and the quicklime (calcium oxide), which produces hydrated lime (calcium hydroxide). The reaction generates considerable heat. For a satisfactory result the amount of water used and the way of adding it needs careful control.

Hydration can be done by hand methods which are suitable for very small scales of production, or in a mechanized hydrator. Hydrated lime is normally produced in the form of a dry powder, suitable for bagging, but some limeworks also produce lime putty, a plastic mixture of lime and water suitable for mortar making. Hydration methods are discussed by Wingate (1985), Spiropoulos (1985), and UNIDO (1987).

4.3.2 Pozzolanas

The technology for producing pozzolanas varies with different types of pozzolana. Calcined-clay pozzolana is manufactured by moulding the clay into bricks or clay balls which are dried, fired in a kiln, and later pulverized. The methods of clay preparation, moulding and firing are identical to those for brick production, except that the temperature of firing is generally somewhat lower than for bricks. Indian Standard IS:1344-1981 gives the following range of temperatures for different types of clays:

Montmorillonite type600° to 800° C
Kaolinite type 700° to 800° C
Illite type 900° to 1000° C

To control the temperature accurately, a downdraught kiln may be employed (see section 2.3). More generally, calcined-clay pozzolana is derived by sorting suitable material from the fired products of brick and tile kilns. In the case of tile manufacture, broken or rejected tiles are used. The calcined clay is then reduced to a fine powder by means of a hammer mill, pulverizer or ball mill.

Fly ash pozzolana does not require any processing. It is selected from the waste ash from power stations so that its fineness and physical properties satisfy certain performance standards set out in section 4.4.

Rice husk ash pozzolana is either field-burnt or subject to controlled calcination. Field-burnt ash, that derived from uncontrolled burning or from boilers, is generally calcined at too high a temperature to achieve maximum reactivity, but it is used in some processes for manufacturing lime-pozzolana mixture. Controlled calcination is achieved in a special incinerator. Different processes have been developed. Typically a bank of four identical incinerators of approximate internal dimensions 1 m x 1 m x 1 m may be used, giving a daily output of 1 ton of ash. The temperature of the ash needs to be monitored to ensure that the temperature does not exceed 600° C (Cook, 1984).

Processing volcanic-ash pozzolana involves extraction, screening, drying and sometimes pulverising. The methods used vary. Some particular examples are described in section 4.6.

4.3.3 Lime-pozzolana binders

Lime-pozzolana binders are produced by intergrinding or blending the separate raw materials, lime and pozzolana. Where the lime- pozzolana mixture is to be sold in bagged form as a masonry cement, it is essential to achieve the greatest homogeneity possible, which is achieved by a lengthy period of intergrinding in a ball-mill. Periods of intergrinding of up to eight hours are used.

An alternative way to use lime-pozzolana mixtures is in the manufacture of concrete, mortar or blocks on site. Used in this manner, the lime and pozzolanas are treated as separate ingredients, and blended by hand mixing or using a drum or pan mixer, along with any other dry ingredients, sand or aggregate, immediately before adding the mixing water. Blending in this manner results in a loss of homogeneity and fineness, compared with milling, but it is simpler, and it can result in mortar or concrete products of acceptable quality.

The appropriate proportions of lime and pozzolana depend on the quality of the two materials. The pozzolana:lime ratio may range from 3:1 to 1:1.

4.3.4 Blended cements

Blended cements are produced by intergrinding or blending Portland cement or cement clinker, pozzolana and other ingredients. Intergrinding using a ball-mill is the usual technology as full homogeneity can easily be achieved. Blending of dry powders is difficult to achieve. Blending in the cement factory to produce a standard Portland-pozzolana cement is one common technique for which standards exist (see section 4.4). Another technique is to intergrind Portland cement, in the form of powder or clinker, with local pozzolanas or other raw materials, in a special grinding plant. This method is used where Portland cement has to be imported at high cost, and its use can be extended by the addition of locally available raw materials. These may be pozzolanic or inert materials used as fillers. The properties of the resulting cement will vary accordingly. No formal standards for this type of material exist. Some particular examples are described in section 4.6.

4.3.5 Gypsum plaster

Calculation

Gypsum plaster is produced by heating raw gypsum to temperatures between 100° and 200° C, which is a much lower production temperature than required for most other low-cost binders. This makes the production technology simpler and the energy costs of production much lower than for comparable materials.

Gypsum is calcined either by burning it, i.e. mixing it with the fuel of combustion and subjecting it to direct heat, or by cooking it, i.e. indirectly heating it within a container.

Direct heating

Methods of direct heat calcining include:

(a) Gypsum fires (see figure 4.2). The crudest and oldest method of calcining gypsum is to make a bonfire from gypsum mixed with fuel and to burn the gypsum for several days. This is done either in a conical pile, or by digging a pit into the ground (for example the traditional dug-out kilns of the Touggourt area of Algeria), or by digging a hole for fuel into surface gypsum deposits;

(b) Gypsum kilns. A slightly more efficient and controllable method of burning gypsum is in a shaft kiln (see figure 4.3). Vertical shaft kilns are easily constructed and have been commonly used wherever gypsum occurs. A cylindrical shaft of between 1 and 2 metres diameter and perhaps 4 metres high is constructed from stone or brickwork, with a small opening (an eye) at the base. This is then loaded from the top with alternating layers of fuel - charcoal or

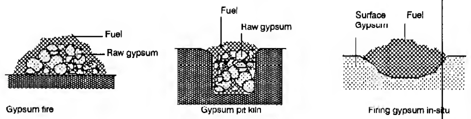


Figure 4.2. Gypsum fires

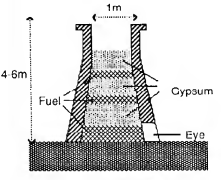


Figure 4.3. Gypsum shaft kiln

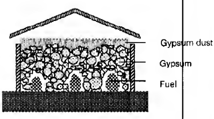


Figure 4.4. Gypsum walled kiln

coal - and raw gypsum. After several days firing, and after cooling, the gypsum is unloaded through the eye at the base and the kiln is loaded for another batch. A shaft kiln of this sort produces a batch of 20 - 50 m^3 of gypsum plaster at a time.

Much larger batches can be fired in a walled kiln (see figure 4.4). This is a rectangular building with perforated walls for ventilation, in which gypsum is stacked for firing. Walled kilns were commonly used in many parts of Western Europe up until the 1950. They are suitable for large-volume, basic-grade gypsum plaster production. Within the large internal space of the walled kiln several crude vaults are built from the pieces of rock gypsum from the quarries. This is a relatively skilled job and labour intensive. On top of the vaults, layers of gypsum are placed with smaller pieces towards the top, and finally topped by a layer of gypsum dust. The fuel is placed in the vaults and the whole construction is fired. Walled kilns can be built as large as required and can produce batches of hundreds of cubic metres of gypsum plaster at a time. In such kilns, the degree to which the raw gypsum is burned is determined by the amount of fuel mixed with the gypsum. The percentage of fuel to gypsum has to be judged before firing and the setting of a kiln is a relatively skilled operation.

Fired gypsum products

With fired gypsum the end result is a mixture of burned gypsum with the ash of the fuel used. These are mixed together and ground up to make a basic quality of plaster which is grey-white. It is known in different traditions by different names, including *Ash- plaster, Timchent*, and *Goss*.

In the firing, only a proportion of the burned gypsum is likely to be the hemi-hydrate plaster that can be rehydrated and set. Some gypsum is invariably "overburned" (insoluble anhydrite) and some may be raw gypsum that has failed to reach calcining temperature. The amount of the gypsum that has been successfully calcined is determined by the uniformity of the temperatures achieved in the kiln and the homogeneity of the pieces of gypsum being fired. A small amount of overburned gypsum mixed in with the hydrate is useful because it acts as a retarder on the setting time of the plaster, as pure hemi-hydrate sets very rapidly. It is important, therefore,that the resulting burned mixture is carefully mixed together and ground to a powder. Typically, these basic qualities of ash-plaster contain less than 50 per cent hemi-hydrate and they set with a crushing strength of the order of 30 kg/cm^2. These plasters develop their full strength quite slowly but end up very hard-setting.

Indirect heating

Higher percentages of raw gypsum converted into hemi-hydrate can be achieved by more even firing. In order to achieve this, it is necessary to obtain even temperature distributions throughout the kiln, to keep the temperature at a controlled level and to have the raw gypsum in relatively homogeneously sized small particles. It is also an advantage to heat the gypsum indirectly, so that the ash is not mixed in with the final product, and so that the fire can be fed or starved to control temperature. Kilns have been designed to achieve this improved quality calcining. A common example is the furnace-heated kiln (see figure 4.5). This allows batches of gypsum to be loaded into the kiln and heated at carefully controlled temperatures. These kilns can be large and need constant monitoring and stirring of the gypsum, so production is more labour-intensive than other kilns.

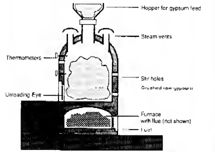
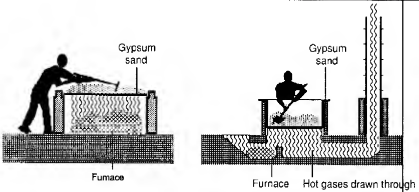


Figure 4.5. Furnace heated batch kiln for calcining gypsum

If rock gypsum is being calcined it has to be crushed before burning to get even sizes of gypsum particles. The process of crushing may involve several stages of operation, including possibly drying before crushing, crushing, screening and grinding. These processes are not needed for gypsum sand. The naturally occurring sand can be dug and calcined by firing or indirect heating (cooking) using relatively simple equipment as shown in figure 4.6.

These simple operations involve stirring the gypsum sands on a heated steel plate until sufficient water has been driven off to form the hemi-hydrate. Because the temperature required is quite moderate, the energy costs of production are low and production is ideally suited to small-scale operations.



Calcining gypsum sand in Cape Verde

Calcining gypsum sand at Noumérate

Figure 4.6. Simple kilns for calcining gypsum sand

Other types of controlled indirect heating include rotary kilns; steel drums which are rotated over a source of heat, mixing the gypsum inside with fixed blades. A simple example of this type of system appropriate for small-scale operations has been developed in the Platna factory in Noumrate, Algeria.

A more sophisticated indirectly-heated rotary kiln, known as the "Four Beau" is the most common type of kiln used for non- pressurized calcining in France today.

Batch production vs. continuous production

Those processes which produce batches of calcined gypsum are most suited to small-scale operations where production can be geared to changing situations and demand for the finished product and supplies of raw material can be variable. Where demand is constant and supplies of raw materials are guaranteed, continuous production is more efficient than batch production. The management and control engineering involved in continuous production is however, much more critical. It is more suited to small-scale industrial operations than to rural or co-operative ventures.

Continuous production kilns involve using pumps and conveyor systems to ensure a constant flow of gypsum through a calcining process. For this, it is best if the raw gypsum is finely ground.

Products of controlled calcining

The calcined gypsum produced by these more controllable methods is a much better quality than the basic quality, directly-fired ash-plaster. It is finer ground, more evenly calcined and ash- free. Additives can be mixed with this relatively pure gypsum to retard the setting time and to give different types of mix. The strength of this improved quality gypsum is considerably higher than the basic. Typical crushing strengths are in the order of 60 kg/cm^2, about twice that of ash-plaster.

Pressurized gypsum production

The hemi-hydrate produced by the above methods of heating in a vessel that is open to the air, i.e. in a dry environment at atmospheric pressure, is known as calcium hemi-hydrate *Variety Beta*. A stronger variety of hemi-hydrate. known as *Variety Alpha*. can be produced by heating the raw gypsum in a closed container, building up a higher pressure in a saturated atmosphere, usually with a saline solution. Hemi-hydrate *Variety Alpha* is considerably stronger than *Variety Beta*. with a set compressive strength in the order of 500-600 kg/cm2; about 10 times that of the Beta. It is also faster setting and is able to be hydrated with much less water, allowing a lower water mix ratio and so developing its higher strengths.

Pressure vessels to produce hemi-hydrate Alpha are known as kettles. Powdered raw gypsum heated under pressure boils and precipitates steam bubbles from the gypsum mass. At temperatures around 150° C, the chemical reactions take six to eight hours. There are a large number of kettle designs, using different types of fuel and methods of heating. At their most sophisticated, continuous production conical kettles are used in the gypsum industries of the developed world. These are highly capital- intensive and require sophisticated control engineering to co- ordinate pump flows, fuel consumption, temperature and pressure. For smaller-scale operations, batch production kettles of proven design are probably most appropriate.

4 4 Performance standards

4.4.1 Lime

Standards divide limes into three different types, according to their chemical compositon. *High calcium limes* are those containing a combined CaO + MgO (lime plus magnesia) content exceeding 65 per cent, but with less than 4 per cent MgO. *Magnesian limes* are those with a combined lime plus magnesia content exceeding 65 per cent with not less than 4 per cent magnesia. *Semi-hydraulic limes* are those with a lime plus magnesia content exceeding 60 per cent, and with a soluble silica content exceeding 5 per cent. These are the definitions of the British Standard BS 890: 1972; slightly different definitions are given in the Indian Standard IS: 712-1984, which distinguishes a further three types of lime, *eminently hydraulic lime*, *kankar lime*, and *siliceous dolomitic* lime. These are limes with larger amounts of silica or magnesia than are accepted in many national standards but which, nevertheless, can be useful for particular building applications. Each of these types of lime can be produced in more than one form. Standards also distinguish *hydrated lime*, *quicklime* and (sometimes) *lime putty*. These forms of lime have been described in section 4.3.

Standards also specify certain physical requirements for limes. The properties usually specified are *fineness*, *soundness* (expansion in setting), *workability*, and *hydraulic strength* (for hydraulic limes only). Full details of the tests are set out in national standards.
4.4.2 Pozzolanas

Standards have been prepared for the properties of pozzolanas to be used as an ingredient of Portland-pozzolana cement or standardized lime-pozzolana mixture (e.g., IS: 1344-1981, *Specification for Calcined Clay Pozzolana*, IS:3812-1981, *Specification for Fly-ash for use* as a *Pozzolana and Admixture)*. Standards also exist for the testing of Pozzolanas (IS: 1727- 1967, *Methods of test for Pozzolanic Materials)*. The properties specified in these standards are *fineness*, *lime-reactivity*, *compressive strength and drying shrinkage.*

The essential requirement for a pozzolana is its ability to combine with lime or with Portland cement and to develop cementitious properties.

Fineness is important because as the average particle size decreases, so the amount of surface area available for reaction increases. Fineness is measured by an air permeability method in which air is forced through a column of material packed to a standard density. The method determines the specific surface in sq m/kg.

The *lime-reactivity* is a measure of the strength of 50 mm cubes of mortar made from a mixture of the pozzolana, a standard lime and a standard sand, after a total period of seven days which includes a period of 48 hours curing at a temperature of 50o C. The compressive strength of the cubes is measured in N/mm2. Drying shrinkage is a measure of the change in length after curing over a period of seven days, as a proportion of the original length.

A *compressive strength test* is also specified when the pozzolana is to be incorporated as an ingredient of Portland-pozzolana cement. The test measures the compressive strength of 50 mm cubes made of Portland-pozzolana cement mortar after 28 days, as a proportion of the compressive strength of cubes made of Portland cement mortar without pozzolana addition.

The details of these tests are complex. They are described in IS: 1727-1967 and other comparable standards. They should only be carried out by an experienced cement testing laboratory. Indian Standards specify two grades of pozzolana according to their performance in these tests, as follows:

Grade I For incorporation in unblended cement mortar and concrete and in lime-pozzolana mixture, and for manufacture of Portland-pozzolana cement.

Grade II For incorporation in unblended cement mortar and concrete and in lime-pozzolana mixture.

Table 4.4. Physical requirements for calcined clay and flyash pozzolanas

Characteristic requirements	Grade I	Grade II
Fineness (specific surface m^2/kg), min.	320	250
Lime reactivity (average compressive strength N/mm^2), min.	4.0	3.0
Compressive strength: Not less than 80 per cent of strength of corresponding plain cement mortar cubes		
Drying shrinkage (percentage), max.	0.15	0.10

Source: IS: 1344 - 1981, IS: 3812 - 1981

Note: Compressive strength test is applicable in case of pozzolana to be used in manufacture of Portland-pozzolana cement only.

An alternative test for pozzolanic activity has been proposed by Allen and Spence (1981) which is simpler to perform in the field. This involves the use of small cubes of 25 mm diameter, which are tested for compressive strength after seven days which includes a period of accelerated curing at 50°. The cubes are made from mixture of 1:2:9 standard lime:pozzolana:standard sand, mixed to a consistency. A minimum strength of 4 N/mm^2 is recommended for pozzolanas which are to be used for mortars and concretes and in lime-pozzolana mixtures.

Indian Standard IS:4098-1967 also exists for lime-pozzolana mixtures, separating them into three classes according to the use for which they are intended. The three classes are as follows:

LP40 For masonry mortars and plasters of grade 30 to 50 kg/cm^2 and for foundation concrete.
LP20 For masonry mortars and plasters of grade 15 to 30 kg/cm^2 and for foundation concrete.
LP7 For masonry mortars and plasters of grade 7 to 15 kg/cm^2.

Tests are specified for fineness (by sieving), setting time, compressive strength, water retention, and soundness. Limitations on free moisture content and loss on ignition are also specified.

The details of the tests are given in IS:1727-1967 and IS:4098- 1967. The requirements are as set out in table 4.6. They should be performed by a competent cement testing laboratory.

4.4.3 Blended cements

National standards exist for the performance of Portland-pozzolana cements. These are based on Portland cement standards and are outside the scope of this document. No formally approved standards for other blended cements exist, but there is a draft standard under consideration in Rwanda to cover LIPORWA, the PPCT cementitious binder produced at Kigali (see section 4.6). The standards proposed are given in table 4.5.

4.4.4 Gypsum plaster

The standards for the production of gypsum products in developing countries are based mainly on the standards published in industrialized countries, for example, the United States (ASTM C472), the United Kingdom (BS 1191), - and Canada (CSA A82.20).

Table 4.5. Proposed standards for LIPORWA blended cement

Compressive strength -	7 days	45 kg/cm^2
-	28 days	90 kg/cm^2
-	91 days	130 kg/cm^2
-	180 days	160 kg/cm^2
Initial setting time (max)		7 hours
Soundness (Le Chatelier) (max)		5 mm
Magnesia content (max)		5 per cent
Loss on ignition (max)		6 per cent
Blaine fineness (min)		3500 cm^2/gm
Retained on 0.08 mm seive (max)		15 per cent

Source: Schilderman (1985)

These standards might provide a model for other blended cements designed to be used for general building applications apart from reinforced concrete.

Gypsum plasters are classified into a number of different categories:

A. Plaster of Paris (hemi-hydrate with no retarder additives)
B. Retarded hemi-hydrate gypsum plaster (hemi-hydrate with retarders)
C. Anhydrous gypsum plaster (or calcium sulphate)
D. Keene's plaster

The tests evaluate the performance of each category of plaster in a number of different properties, described below, and the specifications for each test as set out in the British Standard, BS1191, are summarized in table 4.6.

Table 4.6. Summary of specifications for gypsum building plasters
(British Standard 1191)

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
A. Plaster of Paris	35%	2/3	0.2%	4·9%	5%	2.5	-	-
B. Retarded hemi-hydrate	35%	2/3	0.2%	4·9%	3%	1.2	5mm	0.2%
C. Anhydrous calcium sulphate	40%	2/3	0.2%	23%	1%	-	4.5mm	-
D. Keene's plaster	47%	2/3	0.2%	22%	1%	-	4mm	-

Notes:

[1] Chemical purity. Chemical analysis on the composition of the plaster to determine the proportion of sulphur trioxide in the mixture. Typical minimum levels proposed are shown.

[2] Further tests also determine that calcium oxide is not less than, for example, 2/3 of the sulphur trioxide level.

[3] Control of levels of soluble salts to stop efflorescence in finished wet renders. Chemical analysis determines that soluble salt levels (sodium oxide and magnesium oxide) are below specified levels (typically, 0.2 per cent by weight of the sample).

[4] Organic materials content. A weight-loss-on-ignition test is the standard test for organic and other combustible impurities. Loss- on-ignition limits for the different plasters are shown.

[5] Particle grading. Size of particles in the plaster powder is regulated by the proportion of the sample that fails to pass through a sieve of 1.18 mm. Maximum allowable percentages are shown.

[6] Bending or transverse strength of the set plaster is tested by transverse loading a beam of certain size (25 mm square and 100 mm long) until failure in order to calculate the modulus of rupture in N/mm^2 (0.0072 x breaking load in Newtons for 25 x 25 x100 mm beam). The experiment is repeated six times and an average modulus obtained. Minimum values for averaged modulus of rupture are shown.

[7] Mechanical resistance. The set plaster is tested for its mechanical resistance to impact loads by dropping a steel ball of standard size and weight on to a sample from a specified height. The depth of the impression left by the impact is then measured (taking the average value of 16 measurements). Maximum impression depths are specified.

[8] Expansion on setting. This is only specified for retarded hemi-hydrate plaster used as undercoat and as a finish plaster. Linear expansion is measured using an extensometer. The extensometer has a spring micrometer gauge attached to a triangular cross-section trough into which gypsum is poured and allowed to set. The expansion of the gypsum causes the gauge to deflect. The total expansion after 24 hours is converted to a percentage. Maximum values for percentage expansion are given.

Additional examination of the set plaster for all types is carried out to determine soundness. The physical appearance of samples of set plaster are examined after steaming them for three hours. Standards require that there should be no signs of disintegration, popping or pitting on the surface of steamed samples.

Standards for developing countries, for example Indian standards, use similar tests but with greater emphasis on physical properties than chemical analysis of the product. Indian Standards also set out specifications for gypsum concrete, which is not envisaged in European or North American standards. Tests 5, 6, 7, and 8 and a test for soundness are included in the Indian Standard, with the addition of the following:

(a) *Consistency tests.* Using a modified Vicat apparatus, a plunger rod of a specific weight and cross-sectional area is released into the plaster mix and the penetration distance into the mix is recorded. The penetration is a measure of mixture consistency.

(b) *Setting time.* The time it takes for the sample to change its consistency to a set limit is measured. The consistency tests are repeated at regular intervals until the set limit is reached.

(c) *Compressive strength of set plaster.* Standard cube sizes of set plaster are loaded until failure under compressive load. Tests are repeated five times and the results averaged.

The same standards of quality of product are being sought but through testing the physical and mechanical properties rather than chemical composition. This philosophy is one which can be more widely adopted in countries where chemical analysis laboratories are not readily available to building materials manufacturers.

4.5 Uses in construction

4.5.1 Lime

One of the principal uses of lime in building is as an ingredient of lime-based mortars and plasters, which are discussed in section 4.5.2. Other uses of lime in building are for soil stabilization, in limewashes, and in the manufacture of sand-lime bricks and other lime-based building blocks. Uses of lime are extensively covered in a recent UNIDO publication (UNIDO, 1986).

Soil stabilization

Lime is used in soil stabilization in two different ways. It is very widely used for the stabilization of loose and clayey soils for roadmaking and subfoundation work. At the simplest level quicklime is spread over the top of the ground and then mixed into the top few centimetres of the soil. This changes the plastic properties of the soil, making it easier to compact and enabling it to carry loads. The hydration of the quicklime also absorbs water from the clay. In the long term the lime may react with the siliceous materials in the soil to form strong cementing bonds. This process is accelerated by an increase in ambient temperature, so the technique is especially suitable in warmer climates.

Lime stabilization is also used in the manufacture of stabilized soil blocks as discussed in section 3.2. Again, lime is most effective with clayey soils, which are the most difficult soils to stabilize economically. The process is the same as that described above, except that hydrated lime is normally used. As the strength gain is comparatively slow, where lime is used for soil-cement blocks it is often used in conjunction with cement or a pozzolana.

Limewash

Limewash is a paint based on lime and water which can be used on lime plasters, brickwork, earth walls or other soft surfaces. It is made by diluting a lime putty to a thin cream with water. Colour pigments can be added. Unstabilized limewashes lack durability on external surfaces. There are various formulations by which durability can be improved. A common one is to mix about 8 per cent by weight of tallow to quicklime before it is slaked. Common salt, alum and casein may also be added in small proportions to hydrated lime as stabilizers. A stable limewash can also be made by mixing lime and white Portland cement in equal proportions, but this is an expensive technique, and subject to crazing. The subject of limewashes is discussed in the publication, *Lime in Building (BQSF, 1975).*

Calcium silicate products

Sand lime bricks are made by mixing between 5 and 10 per cent of hydrated lime with damp sand and compressing it into brick shapes which are then matured in a steam oven or autoclave for about seven hours. This produces a hard white brick which requires only about 20 per cent of the energy needed for clay brick production. Lightweight cellular concrete is made by reacting pulverized quicklime and aluminium powder, causing a foam which is mixed with a silica sand aggregate. These are industrialized processes not suitable for very-small bscale operation. They are energy-efficient if a large market for the products exists.

4.5.2 Lime pozzolana binders and blended cements

One of the principal uses of lime pozzolana binders and blended cements is in the preparation of mortars, plasters and renders for masonry work. Lime-pozzolana binders and blended cements may also be used for low-strength concretes and in the manufacture of concrete blocks or stabilized soil blocks. In general, lime- pozzolana binders are not suitable for high-strength applications such as reinforced concrete, as the rate of strength development and the final strength is lower than for concretes made from Portland cement, and deformations are also greater. Under certain circumstances, however, blended cements may be used in reinforced concrete.

A satisfactory mortar needs to possess good workability, adequate strength, good bond, and satisfactory durability. To achieve all these properties, a mortar will generally need to be a mixture of lime with either cement or a pozzolanic material, and sand. Lime is essential to achieve good workability (which incudes the right combination of flow, water retention and cohesiveness), while cement or pozzolana is needed to help the mortar to set and harden rapidly, and to have adequate long-term strength to carry its load. Durability depends on both the strength of a mortar and its porosity, to which both lime and the other ingredients contribute. Plasters require high workability, good adhesion, and strength and durability appropriate to the situation, greater for external than internal work. Concretes for low-strength applications need to have sufficient workability to be able to flow with the aid of vibration or compaction to fill the formwork or mould, and a rate of strength gain adequate to carry the loads of the building as it progresses.

The best mix proportions for any particular use will depend on the binding materials available, the aggregates available, the strength requirements, and the conditions of exposure of the mortar. Standard mix proportions can be specified for the use of lime and Portland cement in mortars, since these materials are produced to widely recognized standards. Pozzolanic materials are of many different types, and standards currently only exist for some of these, so that standard mix proportions cannot be given. Appropriate mixes can be determined for particular local situations from performance standards. Some suggested blends and mixes using pozzolanas with lime and with Portland cement are given in table 4.7, from a recent publication by Bullard (1987), but this gives only an approximate guide which should always be tested with the materials available in any local situation.

4.5.3 Gypsum plaster

By far the greatest use of gypsum in the building industry is in renders and finishes for internal use. Gypsum is, however, a very versatile material and there is increasing interest and activity in using gypsum in a wider range of applications. As a weak binding material, it is increasingly being considered, along with lime and pozzolana products, in strategies for substituting for Portland cement in applications which do not need the strength that Portland cement can develop. Its natural abundance and low production costs make it an attractive alternative to cement for countries that have natural deposits of gypsum. Gypsum has several natural properties, including high thermal insulation, inherent fire resistance and ease of casting or carving that make it attractive for a number of uses. The uses of gypsum in building can be classified as follows:

(a) Wet renders

The oldest and most traditional use for gypsum has been as a wet render or stucco applied to the interior or exterior

Table 4.7. Suggested blends, mixes and uses of alternative cements

Blend	Cementitious material percentage			Total aggregate	Recommended uses	Remarks
	OPC	Lime	Pozzolana			
OPC/ pozzolana	50	-	50	9-12	Low strenght concretes	
	50	-	50	4-8	Mortars and plasters	
	66	-	34	6-10	Medium strength concrete and concrete blocks	
	75	-	25	6-8	Structural concrete	
Lime/ pozzolana	-	34	66	6-8	Low strength concrete and concrete blocks	Ratio of lime to pozzolana may change depending upon quality of lime and pozzolana
	-	34	66	3-6	Motors, plasters and load bearing concrete blocks	
OPC/lime pozzolana	20	-	60	6-9	Medium strength concrete and concrete blocks	In all cases the quality of lime and pozzolana will determine aggregate content
	10	25	65	6-8	Low strength concrete and concrete blocks	
	5	30	65	4-7	Motors and plasters	

Source: Bullard, 1987

of structural walls. Gypsum plaster is mixed with water and trowelled (or possibly sprayed) on to the surfaces. The gypsum render is usually mixed with some sort of fibrous reinforcement to give the flexibility to withstand the expansion and contraction that it experiences with changes in moisture content and temperature. Internal renders are often applied on to a reinforcing layer of fabric, e.g., gauze, calico, jute etc. Traditional additives of fibrous reinforcements like horse hair or straw have been replaced to some extent by plasticizers and expanded metal meshes in modern construction. Gypsum renders externally have been used as decorative features on much traditional architecture in countries of the Middle East and Africa, mainly in countries with arid and semi-arid climates where the solubility of gypsum in water does not pose a problem. In wetter climates, gypsum renders have been used externally with coatings of paint or lime washes to protect them.

(b) Plasterboard

The industrialization of building materials in many developed countries over the past half century has resulted in the widespread manufacture of plasterboard. This is a thin layer of gypsum cast between sheets of paper or board. The paper reinforces the plaster, giving it the strength to act as a single sheet. The technology of production is relatively sophisticated, requiring rolling a controlled thickness of plaster mix between two sheets of paper, usually in a continuous production process, which is then cut to size. The setting rate of the plaster is critical, and drying time is the limiting factor in many production processes. The end product, dry lining for walls and ceilings, has many advantages over traditional wet rendering techniques, including rapid coverage of wall area, semi-skilled installation and no waiting time before applying top finishes. The use of plasterboard for internal lining is almost ubiquitous in larger building contracts in industrialized regions.

(c) Gypsum blocks

Gypsum can be cast as building blocks, either as pure gypsum, or more commonly, as gypsum with an aggregate. Pure gypsum blocks are dense, heavy and brittle and are usually cast as hollow blocks. Aggregates used with gypsum include crushed rock gypsum, limestone or foamed lightweight aggregates. The aggregate makes a lighter block and, if bonded properly, gives additional strength to the block. Gypsum blocks are used traditionally in North African countries and experimentation is currently being carried out on their suitability for wider use in other gypsum-rich countries. The use of gypsum blocks for structural purposes is limited by their loss of strength as their moisture content rises. For infill construction, a major use of concrete blocks, gypsum blocks have many advantages over concrete blocks in thermal insulation and acoustic density.

(d) Gypsum-stabilized earth blocks

Gypsum can also be used as a stabiliser of soil, to improve the binding and durability of soil used in construction. Earth blocks stabilized with gypsum, known as Alker blocks, are used in Cape Verde to build loadbearing walls. Loadbearing walls built of Alker blocks need to be well protected from water penetration (by large overhanging roofs, impervious plinths and external render and other means).

(e) Gypsum mortars

Traditional gypsum mortars have been used in Western Europe for centuries, to build loadbearing walls of rubble masonry, and in North Africa to bind walls of Louz, or sandroses. The mortar sets very rapidly and so has limited workability, but it can be used with block or brick masonry in many situations. Gypsum mortar may not be used in situations where it can become wet, such as in foundation courses.

(f) Gypsum concrete

By pouring a very fluid mix of gypsum plaster over rocks and aggregate within shutters, a very rapid-setting weak concrete is achieved, useful for non-loadbearing applications. Gypsum concrete was used in traditional construction by building up layers of sand and gravel between formwork and pouring in gypsum plaster slurry to form lifts of solid walling.

(g) Precast reinforced gypsum elements

The quality of casting obtainable with gypsum, its sharp edges and crisp definition, are used to produce precast elements for the building industry. In order to develop the necessary strength for a cast element, the gypsum is reinforced. Reinforcement is generally fibrous; vegetable fibre of some sort or, more commonly, in industrial production glass fibre. Cast gypsum reinforced with vegetable fibre is also used traditionally to make centering for arch construction in areas where timber is scarce.

(h) Decorative uses

Gypsum can be carved and cast into intricate shapes which are highly decorative. Commonly used as interior decorative features, such as cornices and ceiling roses among others, they can be cast in continuous forms or precast and installed. Large decorative castings are fixed to the structure by setting metal cramps or frames into the wall, and casting the gypsum around them. Gypsum carving is an art practised in many areas. Very hard gypsum renders are obtained for the traditional relief carving on mosques in the Middle East by compaction after setting, beating by hand in several applications. For wall decoration, gypsum renders mix well with pigments and retarders to form frescoes.

4.6 Innovations in low-cost binder technology

4.6.1 Lime

Raw materials

Recent innovations in the lime technology have included methods of using unconventional raw materials, the design of innovative kilns to reduce fuel consumption or use locally available fuels, and new uses for lime in building or in the manufacture of building materials.

Dolomites and dolomitic limestone are available in abundance. They are attractive materials for lime-burning because the magnesium carbonate dissociates at a temperature substantially lower than does calcium carbonate.

This can, in principle, lead to large savings in fuel consumption. These materials are generally not recommended for small-scale production because there is a danger of unslaked quicklime remaining unless autoclave hydration is used. A method of overcoming this problem was devised in at the Moshaneng limeworks in Botswana, established by the Southem Rural Development Association. The raw material for this works was dolomitic lime-waste from an old mine which was cheaply available as no quarrying was required. The stone was fired in a small vertical shaft kiln of KVIC design (see figure 4.1), using care to ensure that the temperature did not rise above 1000 °C. The quicklime was then platform slaked, and passed through a trommel screen. Only material finer than 0.6 mm was bagged; material smaller than 5 mm was stockpiled to be returned for later screening, and material larger than 5 mm was rejected. In this way unslaked quicklime was virtually eliminated (UNIDO, 1986). The Central Building Research Institute in India recommends, for the same situation, calcination temperatures not exceeding 950° C, and hydrating slowly in an insulated tank for a week (CBRI, undated).

For raw materials to be burned in small shaft kilns, it is important to investigate the stability of the material during firing while undertaking field investigations. A small kiln, with a capacity of 250 kg of raw material, was designed for investigation of potentially difficult limestones in Malawi (Hill, in Wingate, 1985) (see figure 4.7).

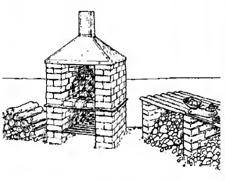


Figure 4.7. Raw materials investigation kiln
Source: Wingate (1985)

Kilns

As with brick kiln technology much of the recent innovation in lime kiln technology has been in South Asia, where lime burning is well-established, and the scarcity of fuel is particularly severe.

In Viet Nam, coal ash from thermo-electric factories and power- stations is available in many places with as much as 40 per cent unburnt coal. This is formed into fuel bricks by mixing with lake mud, and is used in lime-burning using a very small-scale heap- burning technique, without constructing permanent kilns, (see figure 4.8). The kiln is built in alternate layers, 2 - 3 m in diameter, of lime stone and fuel, each layer having a thickness of 150 - 200 mm. New layers are added after the fuel below has been ignited until the kiln reaches a height of 1.5 to 2 m. Insulation is provided around the kiln by building a double wall of unburnt bricks, between which is placed ash and cinder from a previous firing. The same material also forms an insulating layer on the top of the kiln. After firing, the quicklime is hand sorted from the ash and cinder.

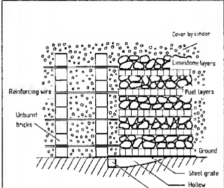


Figure 4.8. Small lime kiln in Viet Nam
Source: Nguyen Tien Dich (1987)

The output from such kilns is 3 to 5 tons, with a burning time of about 36 hours. The fuel consumption is 350 to 400 kg per ton of lime produced. About 7 to 10 people are employed (Nguyen Tien Dich, 1987).

In India, numerous organizations have been active in developing improved small-scale lime kiln designs. The Khadi and Village Industries Commission (KVIC) has developed a range of designs using a well-insulated cylindrical vertical shaft, (see figure 4.1). The kilns are designed to be coal-fired and operated continuously, but they can also be used in a batch firing mode and can use firewood as fuel. A design for burning lime-shells is also available. Designs are available for production scales of 3, 5 and 10 tons per day. When coal-fired, using coal with a calorific value of 22 MJ/kg, fuel consumption can be as little as 12.5 per cent by weight of the limestone. These kiln designs have been widely replicated in India through the training programmes of the KVIC (KVIC, undated). They have also been adopted in several African countries (Spiropoulos, 1985, Spence and Sakula, 1981).

Another design for an output of 10 tons per day has been developed and tested by the Central Building Research Institute. It is a tapering cylindrical shaft, 11 m high, with an internal diameter varying from 1.8 m at the bottom to 3.0 m at the widest point, 6.9 m from the bottom. Above this the diameter becomes smaller again. The kiln is constructed in masonry, strengthened with external reinforced concrete columns. It is loaded mechanically. The objective of the tapering shaft is to improve draught and uniformity of heat distribution. Details of fuel consumption and the extent of diffusion of this technology in the industry are unknown.

Also in India, the firm of Dyerslime and Chemicals Pvt. Ltd. has developed larger kilns for daily outputs of 20 to 40 tons of lime. These are cylindrical shaft kilns of a diameter 3.66 m and a height 12.2 m, constructed of masonry with a refractory lining with an insulating layer between. They are semi automated and designed for semi-continuous operation. Fuel consumption is 1800 to 2000 kcal/kg limestone. This technology is well established and tested (UNIDO, 1987).

The Indian Standards Institute has published standards for the design and installation of lime kilns (IS:1849-1967), and for the manufacture of lime in vertical mixed feed type kilns (IS:1861 1961). These standards have subsequently been subject to various amendments.

In Indonesia, diesel and waste oil are commonly used as fuels for lime kilns, as this is a locally produced fuel. Traditional kilns are adaptations of kilns used for wood-firing, with a single static oil burner inserted into the kiln through an opening in the bottom. This causes very uneven burning and is wasteful of fuel. The Ceramic Research Institute has developed new designs for oil-firing at scales of 6 tons per day and 3-4 tons per day (see figure 4.9) The kilns are constructed from masonry, with a lining of locally produced refractories. The firing system consists of three steam propelled static diffusion burners, which are equally spaced around the kiln. Fuel efficiency of the larger kiln is 1800 kcal/kg. A report describing the kiln and its performance has been published (UNIDO, 1983), but the current state of diffusion of the technology is not known.

In Rwanda, PPCT/COOPIBO have developed a small lime kiln which is fired using peat as the principal fuel (Schilderman, 1985a).

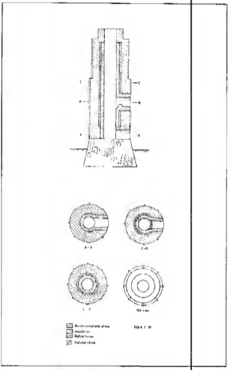


Figure 4.9 Indonesian oil-fired lime kiln
Source: Ceramic Research Institute

In Honduras, VITA developed a new lime kiln design suitable for local construction, (see figure 4.10). The kiln consists of an arched inclined chimney on a slope of 12°. The kiln cross- section is in the shape of a catenary arch of height and base width of 1.8 m, and it has a length of 20 m, with a 5 m high chimney. There are two doors at each end for loading and unloading and every two metres on each side, firing holes for adding wood fuel. The kiln was successfully demonstrated, but the current status is unknown.

Other innovative small-scale kiln designs have been reported by the Building Research Station, Papua New Guinea, Halcrow Carribean and by the Building and Road

Research Institute at the University of Kumasi. A review of some of these kiln designs is given in Wingate (1985).

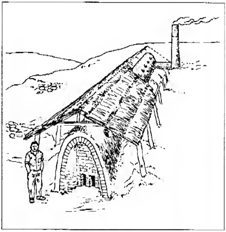


Figure 4.10. VITA inclined chimney kiln
Source: VITA (1977)

Hydration

The Central Building Research Institute in India has developed a small scale mechanical hydrator, for the production of 10 tons per day of dry hydrated lime. The hydrator has three chambers mounted one above the other, and operates at atmospheric pressure. The steam generated during the hydration process is used to heat the incoming water. A wet dust collector is incorporated. It operates with a 7.5 HP electric motor, and weighs about 4 tons. The technology is reported to have been widely replicated (CBRI, undated)

4.6.2 Lime-pozzolana binders

Except in a few countries, such as India and Indonesia, where burnt-clay pozzolana has been in use for a long time, the use of lime-pozzolana binders is an innovative concept. The key importance of binders in every building operation, coupled with the very high costs of installing cement plants, has resulted in an active world-wide interest in possible low-cost substitutes, which can be manufactured on a small-scale using local materials. Experimentation has been particularly active in Asia, and there have been notable innovations in Africa and Latin America.

Rice-husk ash pozzolanas

Binders based on rice-husk ash have been seen as a particularly promising technology for rice growing countries, especially in Asia. Over 20 million tons of rice-husk ash are produced every year, and much of this still goes to waste. Early innovations made use of ash from field burning or boiler ash. The ASHMOH technology, developed by Dr. Kapur and colleagues at the Indian Institute of Technology, Kanpur, involves intergrinding rice-husk ash, hydrated lime and a small proportion of Portland cement in a ball mill for a period of about six hours. The proportions of the ingredients are rice-husk ash 64 per cent, lime 27 per cent, Portland cement 9 per cent. Compressive strengths of 20 to 28 N/mm^2 at 28 days are claimed, although the production average is probably less than this. ASHMOH is bagged for sale as a masonry cement for use in mortars, plasters and low-strength concretes, and concrete blocks (Kapur, undated). The same process was adapted for use in Malaysia where the raw material used was boiler bottom ash.

Experimental work at Asian Institute of Technology, Bangkok, and the University of New South Wales, Australia, has shown that burning at temperatures exceeding 700 °C forms non-reactive crystalline ash, and that uncontrolled burning wastes a high proportion of the potential reactivity of the ash. More recent innovation has concentrated on the development of incinerators for controlled burning. Different designs have been proposed by the Indian Cement Research Institute (CRI), the Pakistan Council for Scientific and Industrial Research (PCSIR), and the Asian Institute of Technology and the University of Khon Kaen, both in Thailand, (see figure 4.11). CRI has developed a complete technology for the production of rice-husk ash masonry (RHAM) cement, at a scale of 2 to 4 tons per day, which has been extensively diffused in Northern India. RHAM cement satisfies the highest grade, LP40, of the Indian Standard IS:4098-1967 for lime-pozzolana mixtures, and is therefore suitable for all construction purposes except reinforced concrete. The extent of diffusion of the technologies developed in Malaysia, Pakistan and Thailand is unknown.

The Regional Centre for Technology Transfer in Bangalore has established a Regional Network to assist in the diffusion of rice-husk ash technologies in the region, which has produced various progress reports. The Intermediate Technology Development Group conducted a review of progress in development and application of rice-husk ash cements in 1983 (Smith, 1984).

Rice-husk ash binders have also been introduced in South America by Servivienda in Colombia. The cement, referred to as CCA, is produced in a number of small factories. Its exact composition is not known, but it is used primarily for the production of concrete blocks (Dalimier, 1986).

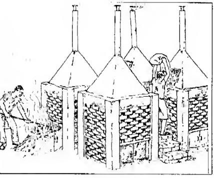


Figure 4.11. Rice-husk incinerators
Source. Spence and Cook (1984)

Plant ashes other than rice-husk ash also offer potential for future use. At the Central Building Research Institute in India, a number of materials have been investigated, including coconut-pith ash, which experiments have shown to be highly reactive with lime when burnt at a temperature of 400 °C. A process of firing the coconut-pith to maintain low temperatures has also been devised. It involves making balls of clay and coconut pith mixed with water, which are strong enough when dried to be stacked in a kiln, or an open clamp, and contain enough organic matter to burn with no added fuel. The resulting plant ash/clay pozzolana satisfies LP7 of the Indian Standard IS:4098-1967 and is suitable for use in mortars and plasters (Dass, 1986).

Volcanic pozzolanas

In Guatemala, Indonesia and several African countries, volcanic ash deposits have been found which are natural pozzolanas. These have been exploited in a variety of innovative ways.

At Lembang near Bandung in Indonesia, a coarse volcanic ash has been used for some years for the production of trass of "batako" blocks. These are made by a hand-moulding process from a mixture of 80 per cent volcanic ash and 20 per cent locally produced lime. The industry is well established, and has received assistance from the Directorate of Building Research in Bandung in the design of improved moulding and handling equipment (Abbas, 1977).

Near Arusha in the United Republic of Tanzania, there are large deposits of a fine volcanic ash, which was used as the raw material for a small production plant which was established by the Small Industry Development Organization with assistance from the Intermediate Technology Development Group to produce a lime- pozzolana binder. The lime was produced in a KVIC-type kiln from a local deposit of surface or kankar limestone, with firewood as fuel, and using platform slaking. The "pozzolime" binder was made by blending ash and lime in equal parts manually. The final product was screened through a 3 mm sieve, and either packed in 20 kg bags for sale, or used to make concrete blocks. Experimental work on the blending and use of lime-pozzolana binders was carried out during a two-year pilot production phase, which has been reported (Sakula and Sauni, 1980). Production from the plant lapsed when management was transferred to the local village, and the current status is unknown. A study was also made of the variability of reactivity of the ash through the deposit leading to some important guidelines for future raw materials investigations (Allen and Spence, 1983). A follow-up study has been made of comparable deposits in Kenya, but so far there has been no use made of them.

At Kigali in Rwanda, an industry has been established producing a volcanic lime-pozzolana binder known as LIPORWA. As this is a blend of lime and pozzolana with cement it is discussed in section 4.6.3 below.

Burnt-clay pozzolanas

Burnt-clay pozzolana is a traditionally used binding material in India where it is known as "surkhi". During the last two decades there have been numerous projects to develop economic processes to produce a reactive "surkhi" having a consistent quality satisfying Indian Standards, which would be cheaper than Portland cement for low-strength applications. These involve firing under controlled conditions, followed by grinding in a ball mill. Processes for production at scales of 2, 5 and 10 tons per day have been developed by the Khadi and Village Industries Commission (KVIC, 1975), but these do not appear to have been widely taken up because the cost advantage relative to the local price of Portland cement has generally been very slight. The National Building Organisation in Delhi developed a fluidized bed burner for the economical firing of clay pozzolana, but this also appears not to have been much replicated. A small downdraught kiln for controlled firing of clay pozzolana was developed and tested by the Auroville Centre for Environmental Studies in Pondicherry (Spence, 1976). The Central Building Research Institute at Roorkee has developed a variety of processes for the production of lime-pozzolana binders based on burned clay as well as other pozzolanic materials (Dave, 1986). The requirement of firing the clay at temperatures exceeding 600 °C makes clay pozzolana an energy-intensive technology, especially when produced at a small scale, and binders based on natural pozzolanas or pozzolanas produced from plant ash will tend to be more economical.

4.6.3 Blended cements

The increased availability of Portland cement worldwide has led to extensive research and development work into the production of cement blends, which would combine the uniformity and rapid strength gain of Portland cement with the use of a filler or extender based on a locally produced raw material. The resulting materials tend to have properties which are intermediate between those of lime-pozzolana binders and Portland cement, to be suitable for low-strength applications and to cost substantially less than Portland cement. In some of these processes the blending material is chemically inert. Intergrinding of ordinary sand limestone or basaltic rock has been practised in Egypt (Galal and others, 1983), and experimentally investigated by the Building Research Centre in Iraq (Ibrahim and others, 1983). Blending of up to 25 per cent burned-clay or fly-ash pozzolana with the Portland cement during cement production is also commonly practised in India, to a national standard for Portland-pozzolana cement.

Blended cements in which materials other than Portland cement dominate the mixture have been produced using a variety of pozzolanic mixtures. In India, the Indian Institute of Technology at Kanpur has developed ashment, a blend of rice-husk ash with Portland cement in the ratio 2 to 1, which can be produced in a small grinding plant at scales down to 500 tons per year (Kapur and Sai, 1980). Some small plants in the vicinity of the Institute were established in 1982, but the subsequent diffusion of the technology is not known.

A blended cement based on Portland cement with rice husk was also developed in Thailand at the Asian Institute of Technology, Bangkok, and at Khon Kaen University. Studies at Khon Kaen University showed that a mixture of equal weights of Portland cement and rice-husk ash, interground for two hours, had strengths at 28 days approaching or even exceeding that of Portland cement (Chindaprasirt, 1983). A pilot plant was built and tested, but there has to date been no diffusion of this technology.

In Botswana, a blended cement known as Setswana Cement is manufactured from 50 per cent Portland cement, 10 per cent lime, 10-15 per cent brick waste and the remainder coal ash. The coal ash and brick waste are local waste products, the lime is manufactured from a waste heap of dolomitic limestone adjacent to the grinding plant, and the Portland cement is imported. The lime, coal ash and brick waste are ground together in a ball mill (locally made) for two hours and the Portland cement is then added. The price is somewhat lower than that of imported Portland cement, and the rate of strength development of the cement is higher. The initial production capacity of 2.5 tons per day is being increased to 40 tons (Shresta, 1986).

In the Philippines, a small voluntary housing association in Cebu has developed a pozzolanic binder using a blend of 70 per cent fly ash, 20 per cent Portland cement, and 10 per cent lime, interground for four hours in a ball mill. The binder is sold for half the cost of Portland cement. Production at a scale of 0.8 tons per day started in 1984 (Pagtambayayong, 1984).

In Rwanda, a local voluntary organization, COOPIBO, has established a small factory for the production of a pozzolanic binder known as LIPORWA. The binder is made by intergrinding a blend of 62.5 per cent volcanic ash pozzolana, 25 per cent Portland cement, and 12.5 per cent lime. The Portland cement is obtained at market prices (at $280 per ton, one of the highest ex-factory prices in the world) from a small factory near Kigali. The lime manufacture is a part of the process and is carried out using a mixed feed vertical shaft kiln which uses peat as fuel. Both limestone and peat are obtained by manual operations from sources close to the factory. The pozzolana used is derived from a volcanic-ash cone located about 40 km away and is of only moderate reactivity. It is dried in a specially constructed kiln and interground with the other ingredients in a vibrating rod mill to a fineness exceeding 3500 cm^2/gm (Blaine). The binder is then bagged for sale as a masonry cement (Apers, Plentinck and Verschure, 1983).

The operation is highly innovative in a number of respects, notably in the design of the blend, the grinding techniques used, and the use of peat as a fuel for a mixed-feed lime kiln. The establishment of the factory in 1983 was preceded by a period of more than six years of experimentation with raw materials, processes and uses, as well as a detailed study of the market for the cement and of production costs. The plant is well established at a small production scale of about 120 tons per month, and the product costs slightly more than half that of the locally produced Portland cement. Considerable effort has been concentrated on the popularization of the binder through demonstration projects, instruction manuals etc. The bags in which LIPORWA is packed also contain instructions for its proper use (Schilderman, 1985, Schilderman, 1985a).

Research into the material's properties has continued since the factory was established, and methods of improving the quality of the product by adjusting the fineness, blending proportions and through the use of various additives have been studied. An expansion of the production plant to an output level of 3,000 tons is now proposed (Schilderman, 1985).

4.6.4 Gypsum plaster

Deposits of rock gypsum are abundant in many developing countries and the number of small-scale production plants for crushing and calcining gypsum plaster is increasing (Suain, 1982). There are small-scale gypsum production industries in the South Asian subcontinent and in many other parts of Asia. In South America, many countries have a rapidly expanding gypsum industry. There is increasing potential for low-capital, small-scale production in many of these regions. Localization of gypsum deposits in some countries does however mean that use will be regional without the transporting of calcined plaster to national markets.

In Cape Verde, simple gypsum pressing plants have been developed for calcining relatively pure gypsum sands. The basis of the technology is a simple rectangular kiln 1.5 x 2.0 m in plan and 1.0 m high (see figure 4.12). The top surface of the kiln is a flat steel sheet made by flattening old oil drums. This surface is heated from below, calcining the gypsum in about 30-45 minutes, during which time it is turned over with a wooden rake. Daily production capacity is about 1 ton of gypsum plaster; for which 250 kg of firewood is need. The gypsum plaster is used locally in the manufacture of cast-gypsum blocks in simple wooden moulds (see figure 4.13). The technology has been described by Cramer (1979) and Smith (1982). Similar simple cooking plates have been used in Algeria and other parts of North Africa to calcine gypsum sands but with relatively poor fuel efficiency (OCRS, 1982).

Other uses of gypsum are being developed. There is increasing interest in using it for stabilizing soil and using its binding properties in construction as well as its more traditional use as a render and wall liner. At the Building Research Station at Lahore, Pakistan, it has been demonstrated that gypsum mortars can develop strengths that comply with national building codes (Mohammed and Iqbal, undated). The reintroduction of gypsum concrete in building codes in India and its use in construction in Algeria show that there may be wider applications for uses of low- strength concrete. The development of higher technology reinforcing methods for gypsum products has led to the use of precast gypsum construction elements in buildings (CSTB, 1985), and development is continuing on reinforcement and aggregate additives for precast gypsum in wider use in construction. (OCRS, 1982, and Blakey, 1961). Experimentation on stabilizing soil blocks by the Department of Building Research in Ankara and in REXCOOP programmes of the French Government (Kafescioglu 1984, Nolhier 1986), have shown that the lifespan of adobe blocks can be considerably prolonged at little increase in cost by the addition of gypsum as a stabilizer.

There is widespread interest in many developing countries in the increased use of gypsum as a substitute for cement in casting building blocks and other prefabricated products. Experiments in North Africa are continuing on the reinforcement of gypsum castings with steel, although there are inherent problems of bonding. Prefabrication plants in Senegal have been used to produce a number of housing developments and public buildings using reinforced gypsum cast units on a ferro-cement framework.

The pace of economic development of many developing countries means that the proportion of buildings requiring higher quality finishes is increasing. The potential for small-scale and low- capital-investment gypsum plants to expand into producing render finishes and plasterboard in the longer term is considerable.

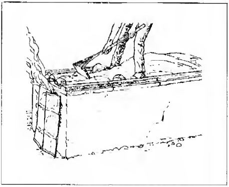


Figure 4.12. Small gypsum plaster kiln in Maio Island
Source. Smith (1981)

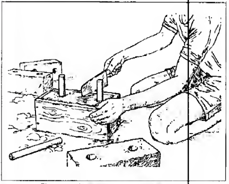


Figure 4.13. Casting gypsum blocks, Maio Island
Source. Smith (1981)

Further reading

Lime

Boynton, R.S., *Chemistry and Technology of Lime and Limestone* (Chichester, John Wiley and Son, 1980).

Groupe de recherche et d'échanges technologique, *La Chaux: sa production et son utilisation dans l'habitat* (Paris, 1985).

KVIC, *Lime Kiln Designs* (Bombay, n.d.).

Spiropoulos, J., *Small Scale Production of Lime for Building in Developing Countries: a Guide to Project Design and Implementation* (GATE, 1985).

United Nations Industrial Development Organization, *A Mini-Lime Plant Manual* (to be published).

_______________ *Lime in Industrial Development*: a UNIDO Guide to its Uses and Manufacture in Developing Countries (IS.555) (Vienna, 1986).

Wingate, M. (ed.), *Small-Scale Lime-burning* (London Intermediate Technology Publications, 1985).

Pozzolana-based binders

Apers, J., Pletinck, M., and Verschure, H., A pozzo-lime cement industry in Rwanda, in *Appropriate Building Materials for Low-cost Housing*, vol. 2 (London, E. and F.N. Spon, 1983) p.86.

Cook, D.J., *Rice Ash Cements: Their Development and Applications* (Vienna, United Nations Industrial Development Organization, 1984).

Hammond, A.A., Pozzolana cements for low-cost housing, in *Appropriate Building Materials for Low-cost Housing*, vol. 1 (London, E. and F.N. Spon, 1983) p.73.

KVIC, *Lympo* (Bombay, 1975).

Smith, R.G., *Rice Husk Ash Cements: Their Development and Applications* (Vienna, United Nations Industrial Development Organization, 1984).

Spence, R.J.S., *Small-Scale Manufacture and Cementitious Materials* (London, Intermediate Technology Publications, 1980).

Spence, R.J.S., and Sakula, J., Pozzolime as an alternative cementing material, in *Appropriate Technology in Civil Engineering* (Lonodn, Thomas Telford, 1987).

United Nations Centre for Human Settlements (Habitat), *The Use of Selected Indigenous Building Materials with Potential for Wide Application in Developing Countries* (Nairobi, 1985) (HS/83/85/E).

Blended cements

Chindaprasirt, P., *Low-cost Cement for Rural Areas* (Khon Kaen University, Faculty of Engineering, 1983).

Eldarwish, I.A., and Shehata, M.E., The use of blended cement in concrete, in *Appropriate Building Materials for Low-cost Housing*, vol. 1 (London, E. and F.N. Spon, 1983) p.137.

Galal, A.F., Portland-basalt mixed cement, in *Appropriate Building Materials for Low Cost Housing*, vol. 1 (London, E. and F.N. Spon, 1983) p.84.

Kapur, P.C., and Sai, A.S.R., *Ashment Cement* (Kanpur, IIT, 1980).

Kawiche, G.M., Production of Portland-Pozzolana cement in Tanzania, in *Appropriate Building Materials for Low-cost Housing*, vol. 2 (London, E. and F.N. Spon, 1985) p.97.

Gypsum

British Gypsum, *The White Book: Technical Manual of Building Products* (Nottingham, 1986).

British Standards Institution, *Specification for Gypsum Building Plasters, BS 1191 : Part 1 : 1973* (London, 1973).

Centre scientifique et technique du bâtiment, *Construire en plâtre dans les pays en développement,* Extrait du Magazine CSTB No. 36 (Paris, 1985).

Groupe de recherche et d'échanges technologique, *Le plâtre: sa production et son utilisation dans l'habitat, Dossier technologies et développement* (Paris, Ministère de la Coopération et du Développement, 1982).

Nolhier, M., *Construire en plâtre* (Paris, L'Harmattan, Villes et Entreprises, 1986).

Organisation commune des régions sahariennes, *Le plâtre dans la construction au Sahara* (Algiers, 1982).

Smith, R.G., Gypsum, Chapter 9 in R.J.S. Spence (ed.), *Lime and Alternative Cements* (London, Intermediate Technology Publications Ltd., 1974).

Spence, R.J.S., and Cook, D.J., Gypsum, lime and pozzolans, Chapter 6 in *Building Materials in Developing Countries* (Chichester, John Wiley and Son, 1984).

Equipment manufacturers and suppliers

GERMANY, FEDERAL REPUBLIC OF

Mannesmann-DEMAG AG
Huttentechnik
Forstrasse 16
D-4000 Dusseldorf
Lime kiln systems

Eberhardt Gmbh
Postfach 1266
D 3340 Wolfenbuttel
Lime kiln systems, shaft

Maerz Ofenbau Gmbh
Postfach 5406
D-4000 Dusseldorf 1
Lime kiln systems

INDIA

Dyers Lime and Chemicals Pvt Ltd
10, Alipur Road
Delhi 110054
Shaft kilns

ITALY

Fercalx S.R.L
Via Bergamo 43
I-24047 Treviglio
Lime kiln systems, shaft kilns and hydration equipment

SWITZERLAND

MAERZ OFENBAU AG
Richard Wagner Strasse 28
CH-8002 Zurich
Lime kiln systems, shaft kilns

UNITED KINGDOM

Baird and Tatlock
Freshwater Road
Chadwell Heath
Essex
General laboratory equipment

Engineering Laboratory Equipment
Eastman Way
Hemel Hempstead
Herts HP2 7HB
General laboratory equipment

Sturtevant Engineering Co
Hamlyn House
Highgate Hill
London N19 5PP
Hydration systems, crushing and grinding plant

Wykeham Farrance
Weston Road Trading Estate
Slough
Berks SL1 4HW
General laboratory equipment

UNITED STATES OF AMERICA

Azbe Corporation
St Louis
Missouri
Lime kiln systems

Chapter 5

Fibre-cement roofing (FCR)

5.1 Introduction

The use of fibre to improve the properties of a cement-based product is well known, mineral asbestos fibre mixed with cement being one example. The use of high-modulus synthetic fibre to increase the tensile strength of concrete has also been well researched and has numerous industrial applications.

This chapter discusses the use of low-modulus vegetable fibre mixed with cement and sand to form a roofing material known as fibre-concrete roofing (FCR). The chapter is limited to applications of FCR aimed at providing a low-cost, durable roof cladding material which can be produced in a developing country using locally available raw materials and resources.

Early developments of FCR concentrated on the production of large sheets in order to simulate the closest known technology, asbestos cement roofing sheets, using fibres to reinforce a rich sand/cement mortar. These large sheets were found to be too heavy to install easily by hand and too weak in bending strength to withstand their own and imposed loads.

To overcome these problems the size of the sheets was reduced to 1 sq m, or slightly less and in this form the technology was implemented, with only minor variations in 17 countries worldwide (SKAT, 1987). In 1983 the size format of the FCR product was reduced again with the introduction of 500 x 250 mm pantiles, the small size allowing a thinner product due to lower self loads.

In recent years the FCR technology, particularly in the tile form, has seen rapid growth and acceptance. For instance, it is estimated that in Kenya and Uganda alone there are over 60 small scale plants producing FCR tiles, with the capability to manufacture over 250,000 sq m of roofing per year. Parry, the main supplier of the FCR tile producing kits, has sold over 600 units worldwide since 1983 with a theoretical output of over 2 million square metres of roofing per year. In addition, FCR is beginning to receive government approval with the introduction of a Kenya Bureau of Standards Code for FCR tiles and official acceptance by the Government of Ghana of FCR tiles as a durable roofing material.

5.2 Raw materials

Cement

Ordinary Portland cement (OPC) conforming with BS 12 or a similar standard is the cementing material recommended in the production of FCR products. The OPC used should be of the highest quality available and cement suspect in quality should be discarded. The cement should be fresh - ideally less than one month old as the quality of cement deteriorates with time. Care should also be taken to ensure the cement has not been stored in damp conditions as even storing in moist air will adversely affect cement quality.

In general, masonry and pozzolanic cement should be avoided as their use will result in a longer production period due to slower setting times and a lower strength product. However, some standards allow the addition of small quantities of pozzolanic material to OPC at the cement factory and this type of cement is normally acceptable for FCR products.

Sand

Sand is an important ingredient in the production of FCR and its quality should not be taken for granted. The use of poor quality sand will result in weaker and often porous FCR products. The best quality FCR products are produced from clean, well graded, angular sand with a maximum particle size of 2 mm. Boonstra (1985) suggests that sands with between 35 per cent and 40 per cent of their particles in the 0.075-0.25 mm range and with no particles below 0.075 mm or above 2 mm should produce high strength FCR tiles. However, in practice, particularly in developing countries, a selection of sands is not often available and an FCR producer is normally forced to use any sands which are locally available. In this case a guide to sands which are not suitable is more helpful than data defining the ultimate grading curve.

Sands with above 5 per cent clay and silt content are to be avoided as are sands with a predominance of single-sized particles. If sands with these characteristics are the only ones available they can still produce acceptable quality FCR products if the clay and silt are washed out in the former case and if they are mixed with a different type of sand in the latter. If all else fails then an increase in the cement content to the mix will produce a reasonable quality product with all but the very worst sands. However, this step should be taken as a last resort as it will significantly increase production costs.

Fibres

A wide range of vegetable fibres has been tested and found to produce an acceptable quality FCR product. Parry (1985) states that only those fibres which have the following properties are unsuitable:

- Stiff fibres
- Oily or greasy to touch
- Impregnated with cement-affecting chemicals (e.g. sugar)
- Susceptible to large dimensional changes when changing between wet and dry state.

In practice, however, sisal and coconut coir are by far the most commonly used with abaca, jute and palm-nut used to a lesser extent. Preparation of fibre involves washing, drying and separating. In some cases boiling may be necessary to remove cement-retarding chemicals. It is often possible to purchase fibre prepared for other purposes, such as sisal for ropes and coir for brushes and mattresses. Man-made fibres such as polypropylene can be successfully used if they are available at a competitive cost.

Parry (1985) suggests the following method for testing the suitability of a fibre. The sample fibre is chopped up and mixed in a sand cement mortar weighing 100 times the fibre weight. It is then left to set overnight. Next day it will be seen that some fibres protrude from the concrete. If these can be pulled out very easily or if the concrete surrounding the fibre is discoloured or powdery, then the fibre is unsuitable, probably because of a contaminant such as sugar.

The draft Kenya standards on FCR tiles (Kenya Bureau of Standards, 1987) states that fibres used in FCR should have the characteristics shown in table 5.1.

Table 5.1. Fibre specifications for FCR from the draft Kenya standards

Characteristic	Average value	Minimum value
Density KN/mm^3	12	9
Tensile strength (N/mm^2)	600	200
Modulus of elasticity (N/mm^2 x 10)	2.6	0.9
Strain (ultimate) (percentage)	3.3	1.0

Water

Generally, water which is suitable for drinking is recommended for the manufacture of any cement-based product. The use of water containing impurities could result in slower setting times and a weaker product. If there is doubt about water quality from a particular source it is recommended that specimen products are made and their setting time and strength compared with samples produced with clean water.

Optional additives

The range of optional additives that can be included in FCR mortar mixes are similar to those used in conventional concrete technology. They include accelerators, plasticizers, waterproofing agents and colouring pigments. Of these only colouring pigments are commonly used in FCR products, normally in the form of iron oxide to produce red tiles. However, a case could be made for the use of all the other additives mentioned, if they are available at a reasonable cost as they will produce higher-quality FCR products and/or assist in the production process. The economic and technical viability of using additives will be site specific and would require individual evaluation. Any additives used should comply with a relevant standard.

5.3 Production technologies

The production technologies for FCR tiles and sheets, although basically similar, differ slightly and will therefore be dealt with separately; a typical technology is described in each case.

5.3.1 Tiles

Preparation of materials

The sand is sieved using a 2 mm sieve. Only the fraction passing is used. If the sand contains above 5 per cent clay and silt, washing will be necessary. The fibres are chopped to an average length of 15 mm with a maximum length of 20 mm and a minimum of 10 mm.

Moulding

1. Cement and sand are mixed dry in the proportions of 1:3 (cement:sand) by weight.
2. 0.75 per cent by weight (of the cement and sand mixture) of chopped fibre is added and mixed in to provide even distribution.
3. Water is added and mixed with the dry fibrous mortar taking care not to add an excess of water.
4. The hinged frame on the vibrating table is lifted and a polythene interface sheet is placed on the table. The frame is then closed and locked in position.
5. A measured quantity of mortar is placed on the vibrating table and is vibrated and screeded for approximately 40 seconds until a flat, smooth and even surface is achieved (see figure 5.1).
6. A small quantity of the fibrous mortar is used to form a nib and is vibrated for a few seconds to ensure bonding to the tile.
7. A galvanized wire loop is then pushed into the nib. This loop acts as a fixing device and is nailed to secure the tile to the batten. Alternatively, a hole can be made in the nib itself by pushing a nail through the nib.
8. The metal frame on the vibrating table is unlocked and lifted.
9. The polythene interface sheet under the vibrated mortar is lifted and thus the mortar is transferred to the pantile mould. Care is taken in aligning the wet mortar on the mould to ensure the correct shape of the finished pantile.

Curing

10. The mortar is allowed to harden on the mould for 24 hours away from any heat source. In hot dry conditions polythene sheeting should be placed over a stack of moulds to increase humidity which prevents rapid drying leading to unacceptable cracking.
11. After 24 hours the FC tile is carefully removed from the mould and interface sheet and the edges of the tile "cleaned off" with a knife.
12. The tiles are then cured underwater for a minimum period of seven days.
13. The tiles are removed from the water and allowed to dry and air cure for a further 21 days, preferably in the shade.

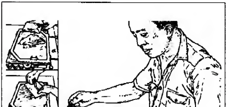


Figure 5.1. Fibre concrete tile moulding - the Parry process
Source: ITDG

Energy requirements

In this technology the electrical motor in the vibrating table requires only 50 watts and is normally powered by a 12-volt car battery. Mains electricity can be used via a 12-volt battery charger (to reduce the voltage and to convert from AC to DC). No other energy sources are required.

Output range and costs

The output range in terms of tiles per day depends largely upon the number of moulds that are available (each tile must cure on a mould for 24 hours). Experience has shown that as many as 300 tiles can be produced on one vibrating table in one eight-hour shift with four workers. At this rate of output quality often suffers and a maximum specified output of 240 tiles per day is more realistic. If more moulds were available a shift system could be used and in theory as many as 700 tiles could be produced from one vibrating table in 24 hours. Another method of increasing output is to use a series of vibrating tables working alongside each other so that say five tables and 1,000 moulds could produce 1,000 tiles per day.

Total production costs including all fixed and variable costs are normally in the range of $US 0.15-0.30 per tile or $US 2.00-4.00 per sq m of roof cladding. These figures will vary depending upon local conditions.

5.3.2 Sheets

Preparation of materials

As for tiles.

Production procedure

1. The mixing procedures are as for tiles except that the cement: sand proportion is 1:1 by weight and the fibre content is 1 per cent by weight.
2. A polythene interface sheet is placed on the table between baseboard and frame.
3. Mortar is placed on the table, trowelled to form a level surface and vibrated by tamping the table frame with the tamping bar.
4. The table frame is removed and the mortar mix is transfered to the corrugated mould with the interface sheet by tilting one end of the baseboard and sliding the mix on to the mould, taking care to ensure correct alignment (see figure 5.2).
5. Hardening and curing procedures are as for FCR tiles.

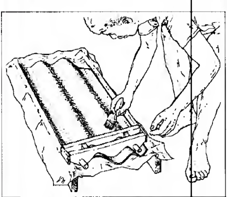


Figure 5.2 Fibre concrete roof sheet manufacture in Sri Lanka
Source: ITDG

Energy requirements

Other than human power there are no energy requirements.

Output range and costs

The process described above is the method of producing sheets developed by Parry. Reported daily outputs using the Parry method range from 10 to 30 sheets per day. Outputs quoted from similar production methods developed in Kenya, the United Republic of Tanzania and Zimbabwe range between 4 and 20 sheets per day (Sakula, 1982).

Material and labour costs would be typically $US 2.00 per sheet with fixed costs adding between $US 0.20 and $US 1.00 depending upon the type of production facility. Thus FCR sheet cost per square metre of roof cladding will normally vary from $US 3.00 to $US 5.00.

5.3.3 Commercial technologies

Tile production

There are only two known commercial suppliers of FCR tile production equipment, Parry and Associates in the United Kingdom and ECO Systems of Malawi.

The Parry equipment comes in two forms, electrical or hand powered, which are supplied with 50, 100 or 200 plastic moulds depending upon the daily output required. The Parry kits also contain a number of accessories - batching boxes, quality- control jig, balance, plastering trowel, small sieve, interface sheets and an instruction manual.The product is a 500 x 250 x 6 mm pantile with a maximum daily output of 200 tiles. The labour force requirement is a minimum of three.

The ECO Systems equipment is hand powered and is supplied with one "mother mould" from which the purchaser produces his own concrete moulds. A number of accessories similar to Parry's are also supplied. The tiles produced on this equipment use a 1:2 cement:sand ratio and are 600 x 285 x 6 mm in size. The maximum daily output is 120 tiles with four workers.

Sheet production

There is no known commercial equipment supplier for sheet production on a small scale. The equipment required is very simple and can normally be made to order. Those organizations mentioned in chapter 7 with expertise in sheet manufacture will be able to offer advice. Sakula (1982) describes four sheet- making technologies.

NFC from Sweden offers a technology package for producing FCR sheets on a large scale (400 sheets per day). Little is known of this technology other than the sheet size, 1200 x 733 x 8 mm and the cement:sand ratio used of 1:3 plus a special additive.

5.4 Performance standards

5.4.1 Technical specifications

The technical specifications of FCR sheet and tiles vary slightly depending upon the manufacturing process involved. Table 5.2 gives typical figures:

Table 5.2. Technical properties of FRC sheets and tiles

Properties	Sheets	Tiles
Actual size (mm)	1000 x 850 x 10	500 x 250 x 6
Shape	Corrugated pantiles	Sheet
Covered area (mm allowing for laps)	850 x 700	400 x 200
Unit weight (kg)	20	1.7
Weight per sq m covered	32	22
Units per sq m covered	1.68	13
Cement:sand proportion	1:1	1:3
Cement content per sq m covered (kg)	17	6
Sand content per sq m covered (kg)	17	18
Fibre content per sq m covered (kg)	0.05	0 018
Water:cement ratio	0.5	0.55

5.4.2 Performance standards

Any roofing material should possess the following properties:

(a) Imperviousness to the elements (rain, snow, hail, sun, wind etc.);

(b) Strength sufficient to withstand loads during transporting, handling, installation and in situ on the roof;

(c) Possibility of access by humans to the roof for repairs etc.;

(d) Permanence of appearance (i.e. colour);

(e) Protection protection against penetration from animals (snakes, rats etc.) and humans (burglars);

(f) Suitability for the collection of drinking water.

When relating these desired properties to FCR products there are some points to consider. Some roofing material specifications allow for a person to walk on the roof directly, while others such as clay tiles and asbestos cement sheets only allow a person to walk on the roof with the provision of crawling boards to spread the load. FCR sheets and tiles will come into the latter category. Loads resulting from wind, earthquakes, etc. will obviously vary depending upon geographic location and so no standard will be suitable for all areas of the world. It should be noted that since many loads are evenly distributed and since FCR sheets are roughly eight times larger than FCR tiles, sheets will normally have to withstand greater unit loads than tiles.

Bearing all this in mind the properties that should be specified for FCR products are as follows:

(a) Transverse strength;
(b) Permeability;
(c) Impact strength:
(d) Surface defects;
(e) Colour;
(f) Nib strength.

Other properties which might be specified are:

(a) Dimensions and tolerance;
(b) Fixing devices;
(c) Water absorbtion;
(e) Markings;
(f) Quality and types of raw materials used;
(g) Surface coatings.

A series of tests are summarized below, with suggested specifications for FCR products in areas with wind speeds not exceeding 45 m/s (100 mi/h). These specifications should be suitable for all areas except those liable to earthquakes or hurricanes. In these cases the minimum strengths required for the product and fixings should be increased by an amount proportional to the increased forces acting upon the roof. These specifications will only be sufficient if the buildings, and particularly the roof upon which the products are laid, are constructed to normal codes of practice (e.g., a reduction in roof pitch will result in higher wind loads).

Transverse strength test:

FCR tiles: Compressive testing machine imposes central line load along profile of tile, supported by 50x25mm timber at 400 mm span. Test wet after 24 hours under water.
Minimum standard required: Average 35 kg with minimum of 25 kg.
Source: Kenya Bureau of Standards (1987)

Sheets: Compressive testing equipment or weights impose central line load along profile of sheet, supported by timbers (50x75mm) at 800 mm span. Double allowable load if uniformly distributed.
Minimum standard required: 50 kg non- destructive, 100 kg first cracking
Source: Sakula (1982)

Permeability test:

FCR tiles: 35 mm diameter glass tube, 300 mm long, placed vertically on tile and sealed. Tube filled to 250 mm with water. Drop in water level measured after 24 hours. Drips should not form on underside of tile.
Minimum standard required: Drop in water level should not exceed 13 mm.
Source: Kenya Bureau of Standards (1987)

Sheets: Purpose-made container placed on sheet laid flat. Level of water is maintained at 20 mm above corrugation peak for 24 hours.imilar test to British Standard 4624 for asbestos cement sheet.
Minimum standard required: No actual moisture on underside of sheet. Signs of dampness are permissible.
Source: Sakula (1982)

Impact strength test:

FCR tiles: 0.25 kg weight dropped from a height of 0.5 m. *Minimum standard required:* No cracking.
Source: Kenya Bureau of Standards (1987)

Sheets: 1 kg weight dropped from a height of 1m.
Minimum standard required: No cracking
Source: Parry (1985)

Surface defects:

FCR tiles: Visual inspection of surface. No visible cracks. No holes greater than 2 mm depth, or 5 mm in diameter. Maximum 20 holes greater than 0.5 mm in any 25 mm^2.
Source: Kenya Bureau of Standards (1987)

Colour:
FCR tiles: Intensity of colour should be permanent throughout tile.
Source: Kenya Bureau of Standards (1987)

Nib strength test:
FCR tiles: Tiles supported close to the nib and weight hung from the nib.
Minimum standard required: Nibs should support 20 kg.
Source: Parry (1985)

Fixings strength test:
FCR tiles: Weights are hung from fixing device.
Minimum standard required: Fixings should be able to support 20 kg.
Source: Bullard (1987a)
Sheets: Weights are hung from fixing device.
Minimum standard required: Fixings should be able to support 50 kg.
Source: Bullard (1987a)

5.5 Uses in construction

5.5.1 Technology choice - sheets vs tiles

SKAT (1987) and Boonstra (1985) have attempted to evaluate the relative advantages and disadvangates of FCR sheets and tiles. Both concluded that FCR tiles are a superior product but the SKAT report suggested that in some cases sheets may be a more appropriate choice.

In summary tiles have the following advantages:

(a) Production costs are lower;
(b) Quality control during manufacture is easier;
(c) Larger area of roof coverage is produced per day;
(d) Handling and transportation are considerably easier;
(e) Installation and fixing are more simple;
(f) Less demanding on roof structure - able to take up unevenness;
(g) Smaller stresses exerted on individual units due to smaller spans and lower self weight per sq m;
(h) Replacement of individual units is easier.

The only advantages of sheets over tiles are that the equipment costs are lower (typically around one third of those for tiles) and that their heavier weight increases the resistance to wind suction forces.

5.5.2 Design and practice

For the design and construction of buildings using FCR tiles and sheets normal construction practices for a similar product should be followed - clay tiles in the case of FCR tiles and asbestos-cement sheets in the case of FCR sheets.

Roof structures

Owing to their relative light weight and large size FCR tiles will generally require around 30 per cent less timber in the support structure than clay tiles or conventional concrete tiles. Support structure requirements for FCR sheets are similar to those for asbestos-cement sheets. In comparison with each other FCR sheets and tiles will require a similar quantity of timber in a support structure. However, tiles have the advantage of being able to take up unevenness in a roof structure and therefore require less exacting craftsmanship, as well as being more suitable for the use of uncut timber, for example eucalyptus poles for rafters and split bamboo as battens.

The following specifications summarize the roof structure requirements for FCR sheets and tiles on a normal pitched roof with a span not exceeding 6.5 m and in areas with wind speeds not exceeding 45 m/s (100 mi/h). These specifications are only a guide and will vary depending upon sizes and quality of timber used.

FCR tile and sheet laying

Generally FCR tile and sheet laying is no different from that for conventional roof cladding materials, and is covered in BS 5247. Tile laying is illustrated in figure 5.3. If FCR tiles and sheets are laid correctly it is not necessary to use waterproof membranes such as polythene or bituminous felt under the tiles.

Fixing methods vary. Tiles are normally fixed with a nail either through the wire loop attached to the nib or through

Rafters and/or trusses

Sheets: 150 x 50 mm rafters at 1.8m centres with trussed rafters at 3.6 m centres.

FCR tiles: 100 x 50 mm rafters at 1.2 m centres with trussed rafters at 3.6 m centres.

Eucalyptus poles can be used for either tiles or shoots.

Purlins or battens

Sheets:75 x 50 mm purlins at 0.85 m centres. Split bamboo may be used.

FCR tiles:50 x 25 (or 35 x 35) mm battens at 0.4 m centres Split bamboo may be used.

Pitch

Sheets:15 - 30 (for pitches below 20° the end laps may require sealing)

FCR tiles:22.5 - 35

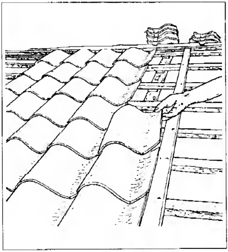


Figure 5.3 Fibre-concrete tile roofing

Source: ITDG

the nib itself. Sheets are normally fixed with galvanized nails, hook bolts or with built-in wire loops. Each sheet should be fixed in a minimum of four places, preferably more, depending upon the fixing method chosen. In areas without high wind speeds it is common practice not to fix tiles, but to rest them on the nib; but it is still advisable to nail all edge tiles. In areas with higher wind speeds all edge tiles and every alternate tile should be nailed. Where hurricanes occur, tiles can be fixed in two places by the addition of a second nib which is nailed to the lower batten.

The construction of hips and valleys is possible with FCR tiles although this is time consuming as each tile will require cutting and shaping by hand using a pair of pincers with care.

In theory it is possible to shape sheets in the same manner although in practice this is almost impossible without the use of a disc cutter. Ridge tiles should be fixed using a weak cement:lime:sand mortar. It is important that the mortar is weaker than the tiles or sheet so that any movement will cause cracking in the mortar rather than the tiles. Walking on FCR tiles or sheets laid on the roof is not recommended without the use of crawling boards to spread the load.

5.5.3 Transporting

FCR sheets are not easily transported, particularly over unsurfaced roads, and losses can be quite high. For this reason it is advisable to produce FCR sheets on the site where they are to be used. Transporting FCR tiles is a much easier operation: they should be packed vertically and tightly on a flat bed, with a bed of sand if the roads are particularly rough. Losses during the transporting of FCR tiles properly packed are very low, normally between 0 and 2 per cent.

5.6 Innovations in FCR technology

5.6.1 Tiles

To date the main supplier of FCR tile making equipment has been Parry and Associates in the United Kingdom which has sold over 500 tile-making kits worldwide since 1983. In the past two years local designs have been developed in India, Kenya, Malawi, Nepal, Sri Lanka, Zambia and Zimbabwe. However, only the Malawian development has reached the stage where it is commercially available. The main innovations worldwide are as follows.

Vibrating tables

The vibrating equipment supplied by Parry and Associates is by far the most tried and tested available with over 450 electrical and 50 hand powered versions in use. The vibration is generated by an eccentric weight revolving at a speed of approximately 50 Hz. Feedback has generally been favourable with few reported breakdowns and only minor problems in quality control. The Parry electrical models are now supplied with a clip-on "Multivibe" vibrating unit which can also produce other vibrated concrete products, such as blocks and pipes, if used with the appropriate moulds. Tiles made on the Parry equipment have formed the basis of the Kenyan Bureau of Standards specifications for FCR tiles.

Parry and Associates also produces a manually-powered vibrating table which will produce tiles in theory at the same rate as an electrical version. In practice the output is normally reduced by around 20 per cent owing to the additional human effort involved. The cost of the hand powered vibrating table is more than the electrical version and it does require an additional labourer. However, it does have the advantage of not requiring any power supply at all other than human energy.

The Rural Housing Programme in Malawi has developed an impact- driven vibrating table which has recently been marketed by ECO Systems in Blantyre. In this design the vibration is produced by rapid impact rather than a revolving eccentric cam as in the case of the Parry designs. This system uses one "grandmother" mould from which the purchaser makes his own concrete moulds, and produces larger tiles with a shallower profile and higher cement content than tiles produced on the Parry equipment. It is considerably lower in cost than the Parry models but its long-term performance and reliability are unproven. Repair and maintenance difficulties are not anticipated as the simplicity of design will allow repair in the most basic of rural workshops. Tiles made on this equipment have been tested at Blantyre Polytechnic, University of Malawi and found to be of an acceptable standard.

The other known developments of vibrating tables are based on the revolving weight principle to produce vibration and are either manual or electrically powered. Those with the greatest potential and most likely to become commercially available are the developments by Development Alternatives in India, HRDU/Thompson and Action-Aid in Kenya, and Ecological Designs in Zimbabwe (see figure 5.4).

Although basically simple equipment, the design and development of a quality vibrating table is not a simple operation and requires research, development and testing over an extended period by a competent engineering workshop.

Moulds

The early tile moulds were made from concrete with an individual wooden frame to allow stacking. These were found to be rather heavy and were replaced by lighter and easily transported vacuum- formed plastic moulds with screw-on wooden strips to facilitate stacking (see figure 5.1).

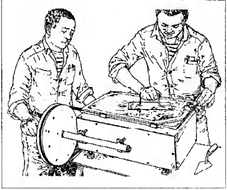


Figure 5.4 Fibre concrete tile manufacture - manual vibrator
Source: ITDG

Later tile mould designs incorporated a curtain type arrangement which sealed the mould below and prevented rapid drying and subsequent cracking of the tile on the lower mould.

More recent innovations include the introduction of high-quality glass-fibre moulds produced in both Kenya and Zimbabwe which although expensive are still able to compete in price with the lower-quality vacuum-formed plastic moulds when transport costs from the United Kingdom are included. Considerable potential exists for the introduction of injection-formed plastic moulds which promise to be of a high quality and, if produced in large numbers, available at a reasonable cost. Plans to introduce moulds of this type are under consideration in both Kenya and the United Kingdom.

At the low-cost end of the scale, concrete moulds are being reintroduced which, despite the disadvantages of greater weight, shorter life and reduced durability, are still economically competitive as their selling price is often only 10 per cent of the plastic or glass-fibre alternatives. Concrete moulds have the further advantage of being able to be produced from a "mother mould" by the tile maker as the raw materials and skills required are commonly available. However, this does introduce an extra quality control element and if the moulds are incorrectly made then there is little hope of producing quality tiles.

Tile shapes

To date FCR tile production has been exclusively of the pantile design; recently Parry and Associates in the United Kingdom have developed two new designs - "Roman tile" and "semi sheet". The Roman tile is the same size as the pantile and is made on the same equipment, although a different moulding frame is required as the tiles are thicker (8 or 10 mm) and different moulds are used. The extra 2 mm thickness is to compensate for the strength loss caused by their flatter profile compared with the corrugated shape of the pantile. These tiles are designed to fit closely together at both the side and end laps giving a more harmonious appearance than the pantiles. The result is a tile aimed at upper income groups and in direct competition with more traditional concrete tiles. Their production cost is likely to be approximately 20 per cent above that of pantiles.

Semi-sheets are larger products with a unit size of 600 mm x 600 mm x 8 mm and a coverage of 0.25 sq m. They use the same "multivibe" vibrator as the pantiles but the table top, moulds and frames are all different. This development is an attempt to combine the advantages of tiles and sheets in one product. Development is still taking place and it is anticipated that a package to produce semi-sheets will be available in 1988.

Ridge, hip, verge and eaves details

Developments in Kenya and the United Kingdom have resulted in improvements in the architectural detailing of ridges, hips, verges and eaves. Ridges and hips can be visually improved by the use of ridge tiles with preformed overlapping joints (see figure 5.5). Previously ridges and hips had been butt-jointed or overlapped without the use of an overlapping or halving joint, neither of which was aesthically pleasing. Ridges can be further improved by the use of preformed water stops to replace bedding mortar.

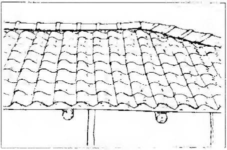


Figure 5.5 FCR tiles: hip and ridge tile details
Source: ITDG

Verges can be considerably improved by the use of half tiles which ensure that the roll of the tile is downwards at both verges. Without these half tiles the verge at the left hand side of the roof will be pointing skywards. Tiles without a lower mitre laid on the bottom row will improve the aesthetic appearance of the eaves. The manufacture of tiles to meet this requirement will require an additional moulding frame.

While these improvements in detail do not affect the structure or waterproofness of an FCR tile roof, they do improve the visual impact and are important if FCR tiles are to compete on an even basis with more traditional concrete and clay roofing tiles.

Additional equipment

Parry and Associates produces a range of additional equipment
including handling trucks, accelerated solar curing bins and fibre cutters (see figure 5.6). This equipment is labour saving and is only likely to prove economically viable in larger production units with an output in excess of 500 tiles per day. The solar curing bins are only really effective in bright sunny weather conditions.

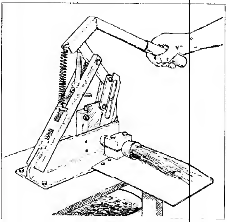


Figure 5.6 Fibre chopper developed by IT Workshops
Source: IT Workshops

5.6.2 Sheets

Sakula (1982) describes FCR roof sheet production in four African countries. Each technique employed differs slightly although the process is basically the same. The main difference between the Parry method described in section 5.3.2 and the other processes is that Parry uses randomly distributed chopped fibre whereas many other methods use long fibres interlaid with the mortar. Thus a layer of mortar is followed by a layer of long fibres which is covered by mortar and then a second layer of fibre is added running at right angles to the first layer. This process results in a sandwich of mortar-fibre-mortar-fibre-mortar and attempts to reinforce the mortar with fibre in a similar way to steel in normal reinforced concrete. Since Gram's (1983) work on fibre durability in concrete, the long-term durability of sheets using this type of production method is questionable and in many areas production has been largely discontinued.

The major development in sheet production in the past five years has been the introduction of semi-mechanized plants by National Fibre Concrete AB, a Swedish company, capable of producing up to 400 sheets per day. The process involves mechanical mixing of the mortar after which the sheets are formed on a production line incorporating a series of vibrating tables. A fibre net is placed in two layers sandwiched between layers of mortar. An additive with the trade name of Acacil is used, the composition of which is not in the public domain. The manufacturers claim it secures safe and quick processing, gives high strength and impermeability and extends fibre life. Only one production facility using this process is known and no production data is presently available.

5.6.3 Fibre vs non-fibre

Recent work in Malawi has shown that thin concrete tiles can be produced without the addition of fibre. This has led to a debate on whether the addition of fibre in concrete roof tiles is advantageous. This argument is further heightened by the fact that vegetable fibres will decay in the alkaline environment of a cement-based composite. The supporters of fibre use argue that this is of little importance as the fibre's role is only active during the early life of the product - to hold the mortar together in the wet state, to control shrinkage-cracking during curing and to increase toughness during transporting and handling when the greatest loads are normally imposed. Those supporting the non-fibre argument point to the facts that fibre can be expensive and difficult to obtain, its use is an extra and unnecessary quality control provision andwhen fibre is added a higher water:cement ratio is required in the mortar which decreases strength and impermeability.

Research has so far been unable to support either argument unequivocally although it is generally accepted that fibre content should be reduced to the minimum quantity that will result in achieving those properties listed above. This minimum percentage will vary, normally between 0.5 and 1 per cent depending upon the type of sand and cement used.

Other research (Gram, 1983) has concentrated on attempting to prolong fibre life by reducing the alkalinity of the mortar and thus allowing the fibre to act as a reinforcing agent. Some promising results have been achieved but long-term vegetable- fibre durability in a cement-based composite is still questionable.

Further reading

Action-Aid, *Roofing with Fibre-Cement Tiles* (Nairobi, Action-Aid, 1985) (unpublished report).

Boonstra, J.L., *Sisal Cement Handbook* (Nairobi, United Nations Centre for Human Settlements (Habitat), 1985) (unpublished report).

Evans, B., *Understanding Natural Fibre Concrete: Its Applications as a Building Material* (London, Intermediate Technology Publications, 1986).

Gram, H.E., *Durability of Natural Fibres in Concrete* (Stockholm, Swedish Cement and Concrete Research Institute, 1983).

Gram, H.E., Persson, H., and Skarendahl, A., *Natural Fibre Concrete* (Stockholm, Swedish Agency for Research and Co-operation with Developing Countries, 1984).

Kenya Bureau of Standards, *Specifications for Fibre Concrete Roofing Tiles*, K502-749 (Nairobi, 1987) (unpublished draft).

Parry, J.P.M., *Fibre Concrete Roofing* (Cradley Heath, Parry and Associates, 1985).

Sakula, J.H., *Sisal Cement Roofing in East and Southern Africa* (London ITDG, 1982) (unpublished report).

SKAT, *Fibre Concrete Roofing (FCR)* (London SKAT/IT Publications, 1987).

Equipment suppliers for fibre-concrete roofing

KENYA

Hagger-kate Services Ltd
PO Box 59280
Nairobi
Agents for Parry and Associates (see entry under United Kingdom)

Sri Raj
PO Box 43490
Nairobi
Fibre-glass tile moulds

C. Thompson
PO Box 34753
Nairobi
Concrete moulds with wooden racking system, tile vibrating table under development

MALAWI

ECO Systems
PO Box 938
Blantyre
Hand-powered tile production unit and concrete moulds developed by Twigt

SURINAME

Hesdy Landbrug
PO Box 5147
Paramaribo
Agents for Parry and Associates (see entry under United Kingdom)

SWEDEN

Natural Fibre Concrete AB
Esplanaden 3A
PO Box 512
S-17229
Sundbyburg
Semi-mechanized plant for FCR sheet production

UGANDA

Magric
PO Box 3218
Kampala
Agents for Parry and Associates (see entry under United Kingdom)

UNITED KINGDOM

Parry and Associates Ltd
Overend Road
Cradley Heath
West Midlands B64 7DD
Range of hand-powered and electrical tile manufacturing units with plastic moulds
Training in tile manufacture

ZIMBABWE

Ecological Designs
PO Box 780
Masuingo
Hand-powered tile manufacturing unit and fibre glass moulds

Chapter 6

Timber

6.1 Introduction

Timber is one of the most valuable resources and it conforms to the most varied requirements. It is easily worked with tools and machines and it has a very high strength to weight ratio. Despite its strength, it is so elastic that steam can be used to make it into complex shapes. Wood is resistant to mild chemicals and it does not corrode.

Timber is also an important element in the industrial economy and the life of rural populations. It can in fact be used at any level of technology for a wide range of purposes from building materials, fencing and furniture, to farm implements, carts and waterwheels and even to carving.

At a higher level of technology, timber is the raw material for a great variety of industries, including saw-milling and the manufacture of products such as plywood, blockboard, particleboard, fibreboard, pulp, paper and paperboard, celluloid and rayon. Many species of tropical hardwoods are greatly appreciated for their decorative nature, their exceptional stability and durability, their freedom from flaws and the ease with which they can be worked.

6.2 Timber resources

Appropriate technology for timber utilization

Proposals have been made for increasing the supply of forest products in many countries or at least of satisfying more needs with the current level of supply. Some of the current techniques for using wood are very wasteful and can be improved by appropriate technology. Timber could be more efficiently used by the introduction of simple techniques for the prevention of decay and insect attack. Many timber species last for only a few years in contact with the soil in a tropical climate. Most preservation treatments are expensive and have to be carried out on an industrial scale. However, there are simple preservation techniques using appropriate technology available both for sawn timber and timber poles.

Much decay and damage can be attributed to wrong conditions of use. For example, untreated timber when placed in contact with the soil remains damp and accessible to fungi. The top of timber structures is often left inadequately protected from the elements so that the timber cracks in the sun and absorbs rain. Improved building design, providing protection from above and below, will ensure greater durability, and the painting of exposed surfaces can further improve performance.

Much may also be achieved by the appropriate choice of tree species. Some of the most durable timbers, such as teak, are now not available freely. Research into the durability of less well- known species, particularly those with high growth rates, may help in the future.

Nomenclature

Timbers are botanically divisible into two classes, "softwoods" and "hardwoods", softwoods being produced by coniferous trees and hardwoods by broad leaved trees. The terms can be somewhat confusing since some softwoods are harder than hardwoods and vice versa. Both classes contain timbers which vary in weight, strength, resistance to decay, and colour. A single species of timber may be found growing in various parts of the world and each country may use a different common name.

A good guide for standard names and botanical names of a major portion of world timbers is in the British Standard publications BS 881 and BS 579: 1974 *Nomenclature of commercial timbers including sources of supply*.

Tropical forests

The most significant feature of the tropical moist forest is the heterogeneity of its botanical composition. This is particularly valid for the South American tropical moist forests as the number of species is very great. For many parts of the African rain forest detailed information on composition and utilization is not available.

There are considerable variations from place to place in the botanical composition of the tropical forest. These local variations entail diversifications in wood properties which have a particularly unfavourable impact on utilization.

FAO (1976) states that in Africa the number of species growing in a given forest is high but a major portion, two-thirds or more, of the standing volume is formed by 20 to 40 species only, out of which very few species may be considered dominant. There are 220 wood species which are more or less known, of which about 100 are regularly used in appreciable quantities, the remainder being used much less. The document lists the properties of 217 timber species found in Africa.

FAO (1978) states that in South America the number of species growing in a given forest is high, but a major portion, twothirds or more, of the standing volume is formed by 30 to 50 species only, out of which few species may be considered as dominant. There are 470 wood species which are more or less known of which about 210 are regularly used in appreciable quantities, the remainder being used much less. The document lists the properties of 473 South American timber species.

Forestry plantations

In the modern world, the policy of the foresters is to plant at least enough land to compensate for extraction and natural wastage. In such an operation trees are planted in close proximity to each other so that in their early stages they grow in a slim, upright form with little development of lateral branches. Since the full potential of the site is about 200 trees per hectare, forming about 20 per cent of the initial planting, thinnings often provide trees of a quite reasonable size which can be used efficiently in the round form (referred to as poles). In addition to the timber obtained from the final crop, the poles obtained from thinnings can be used as a constructional material. The disadvantage of poles is that a high proportion is susceptible to decay. The thick outer sapwood layer, however, is easily penetrated by preservatives.

Forestry has become more of an economic exercise, and it is no longer possible to produce a variety of timber species, regardless of cost, to meet all the market requirements. Foresters tend to concentrate on those species which are the easiest to handle silviculturally, and which will produce the greatest volume of generally useful wood in the shortest time.

In the temperate countries of Europe and South America, where this development has taken place to the greatest extent, the trees which best fulfil these requirements are the conifers or softwoods. In the subtropical countries of Southern Africa, South America and Australasia, forest management has concentrated on softwoods to supply the bulk of timber requirements, and where fast growing conifers have not occurred naturally, exotic species have been introduced. In the tropics, hardwoods have been planted during the last few decades, in addition to softwoods, wherever it has been possible.

Bamboo

Bamboo is one of the oldest building materials used. The use of bamboo is normally restricted to areas where suitable bamboos grow in sufficient abundance. Bamboo grows in many countries in South and South-East Asia, in some countries in Africa and in South America. Bamboo has many advantages as a construction material: it is light, strong and elastic. Only simple tools are required to work with bamboo, and it does not have waste material such as bark and sawdust. However, there are disadvantages such as low durability, fire risk, uneven dimensions and difficulty in jointing. These can be overcome to a great extent with new techniques.

Coconut wood

The coconut palm occurs in all tropical and most subtropical regions, most abundantly in Asia and the Pacific. The development of viable coconut wood utilization requires the following investigations:

(a) The structure and composition of the raw material, with techniques of conversion appropriate to these;

(b) The location and availablity of overmature, diseased and dead stems.

The properties and peculiarities of the coconut stem were summarized at the Zamboanga Coconut Wood Seminar (Philippine Coconut Authority, 1979).

The coconut palm stem has a number of features that makes it unique as a wood source material. Early attempts at utilization were somewhat disheartening because results did not compare well with conventional wood from either hardwoods or softwoods. The development of equipment and technology specific to coconut wood has overcome many of these problems.

Rubberwood

When rubber trees outlive their useful life as far as "tapping" latex for processing into rubber is concerned, they are replaced with new ones. Rubber trees have a useful life of about 25-30 years, and as they are replanted continuously, they represent a constantly growing and important source of raw material. The main problems with rubberwood are blue stain and insect attack. These can be overcome by sawing immediately after felling and dipping into an anti-fungal insecticide solution.

6.3 Processing technologies

6.3.1 Techniques of sawing

The pattern in which timber is converted from a log has some influence on its appearance and behaviour. The end grain of timber is particularly strong and resistant to abrasion; this is highlighted in the use of end grain blocks for flooring. However, end grain surfaces are relatively porous since they expose mostly open cell cavities. This section of wood is therefore vulnerable to moisture pick-up, which in adverse environments could lead to decay.

The way in which a log is sawn is important. If due care is not taken in sawing, valuable timber can be wasted. The process of cutting up a log is known as timber conversion. There are two methods of converting a log and they are:

(a) Through-and-through sawing;

(b) Quarter-sawing

Through-and-through cutting is the simplest method of conversion, as the boards are cut to the desired thickness, parallel to each other on the longitudinal axis of the log. When a log is sawn in this manner, the boards tend to "cup" and attractive grain patterns can be lost. When a log is quarter sawn most of the boards are cut on the radius of the log. When cut in this manner, radial shrinkage is less than when the log is sawn through-and-through. The tendency for the boards to "cup" is also much reduced in quarter-sawn timber. The attractive grain of some woods is shown to advantage when quarter-sawn.

The details of sawing and woodworking are covered in the document *Woodwork Technology* (Strefford and McMurdo, 1978). In sawing timber, different types of saws can be used and these are discussed together with advice on saw-doctoring and maintenance in FAO Forestry Paper Nos. 39 (1982), 40 (1983) and 58 (1985).

6.3.2 Grading

Grading may be carried out to assess the appearance of the timber simply by considering the size and position of characteristics such as knots in relation to decorative requirements. This is appropriate for joinery and furniture. Grading for strength (known as stress grading) must assess the effect of characteristics such as knots on the strength of a piece of timber.

Stress grading is simply the sorting of timber into categories on the basis of predicted strength. It is important if structural timber is to be used efficiently and safely. A number of characteristics of timber which may be considered defects from an appearance grading point of view, such as stain not associated with decay, and pin holes, can be accommodated in structural material with little or no loss in strength. Certain characteristics such as slope of grain, however, require careful limitation, and there are two main methods of achieving this, visual grading and machine grading.

Visual grading assesses the effect of visible features which reduce the strength of the timber. Stress grading machines measure the stiffness of the timber, which is directly related to its strength, and have the advantage of taking density correctly into account, a factor not practicable to the visual grader. Machine stress grading is generally supplemented by visual inspection.

When low-cost housing, simple trusses, prefabricated buildings and bridges are being designed and implemented in developing countries, materials must be selected only at the level of discrimination strictly necessary. At the same time selection must be efficient to avoid waste of valuable resources.

A very brief description of stress grading would probably mention knots, fissures (these include checks, shakes and splints) and slope of grain as being the chief characteristics the size and position of which should be limited. Whilst it is equally important that all of these features should be controlled, together with others enlarged upon in specific rules, it is the various treatments of the measurements of knots that permit a further subdivision to be made of types of visual stress grading rules.

Grading rules have been developed and successfully used in many developing countries such as in Malaysia (Malaysian Timber Industry Board, 1984), in Andean Pact countries (Junta del Acuerdo de Cartegra, 1984), in Papua New Guinea (Forest Industries Council of Papua New Guinea, 1979), and in Fiji (Alston, 1982).

Strength grouping

Owing to the multiplicity of timber species involved in many countries, it has long been a problem to present structural timber data to the end-user in an appropriate fashion. A technique devised to minimize this problem is grouping. Where the structural species of timber used in a country are easily identifiable, and few in number, it may be appropriate that specific structural design properties be published for each of these species. In many countries, numerous species are used and it is not practicable to have long lists of design data. It is preferable to group the timbers and to provide structural design properties for a limited number of strength groups. In general, each strength group will cover a large number of species and a commercial mixture of species.

The use of a limited number of strength classifications is of considerable value to the designer as it enables him to specify timber by a strength group rather than by species. This makes it possible to have a wider choice of timbers from which to select for any specific design. For the producer it assists in the utilization of lesser-known species which may be sporadic and regionally limited in their occurrence. Information on strength grouping is given in publications prepared by TRADA (1985a) for the UNIDO Expert Group Meeting on Timber Construction.

Timber defects

Defects in timber, such as shakes, splints and checks are caused either when the tree is felled or by bad seasoning. Stains and discolourations, due to fungal attack, occur before the timber is fully seasoned. Most common defects are knots, shakes, fissures, interlocked grain, honey combing, cupping, springing, bowing, twisting and distortion. The above defects are described in detail in the Strefford and McMurdo (1978), Desch (1981) and USDA (1974).

6.3.3 Moisture content and seasoning

Timber in the wet ("green") condition contains a large amount of moisture. To enable the timber to give satisfactory service in use, most of this moisture has to be removed. The object of seasoning timber is to remove the extra moisture under controlled conditions with as little damage as possible, thus making the timber more stable. When it is dried, the strength properties and workability of the wood improves and liability to insect and fungal attack decreases. Hygroscopic materials, including wood, have a tendency to change dimensions in response to changes in moisture content, expanding or decreasing as the moisture content responds to changes in relative humidity. This response is referred to as moisture movement.

Wood, drying from the wet ("green") condition which existed in the tree, retains its original dimensions until the contained moisture falls to about 30 per cent of the dry weight of the timber. From this level, known as the fibre saturation point, the wood shrinks as it dries. Similarly, expansion occurs as moisture is increased in dried wood to a maximum of about 30 per cent. Any increases beyond this level will not result in further expansion. Moisture movement can involve distortion such as bow, twist or spring.

For structural work, timber should be dried to within 5 per cent of equilibrium moisture content (EMC). This value refers to the moisture content which would be attained in service. EMC depends upon the relative humidity and the temperature of the surroundings and the following may be considered a rough guide.

	Equilibrium moisture content (percentage)
Hot dry regions (desert, semi-desert and savannah)	10 -12
Tropical highlands (above 1500 m)	12 - 14
Tropical lowlands, rain forests	14 - 18

(Other climatic conditions are not included)

The moisture content of wood may be assessed by several means. Two methods have become established as standard practice, the oven test method and the electrical resistance moisture method. These are fully explained in *Timber Drying Manual (BRE, 1985).*

The two most practical methods of drying timber are air drying and kiln seasoning:

Air drying

In air drying, green timber is stacked in open sheds on a level well-drained site. Stacks are erected on good solid foundations and in order to allow ample ventilation, the bottom layers raised above the ground. Where a concrete base is not possible, the soil under the stack is poisoned with an appropriate insecticide solution. The layers of timber are separated by using piling sticks of clean dry timber, the thickness of the sticks varying from 13 mm to 38 mm depending on the timber species and outside temperatures.

The time required for seasoning will depend on the species and climate of the surroundings. Some softwoods in tropical climates require only six weeks, while some of the denser hardwoods need at least 25 weeks.

Kiln seasoning

In kiln seasoning the timber is placed in a chamber or a kiln in which the temperature, humidity and the flow of air can be controlled to achieve the maximum rate of drying and to reduce the development of defects. The timber has to be carefully stacked so that a uniform air circulation can be achieved. Various kiln schedules have been devised to dry timber as rapidly as possible without the development of defects. Kiln seasoning allows timber to be dried to any desired moisture content appropriate to its end use in a predictable time. A further advantage is that special treatments, such as reconditioning and sterilization, can be carried out using the same equipment. Details of air seasoning and kiln seasoning are given in *Timber Drying Manual* (BRE, 1985).

Other methods of drying

Solar drying uses the sun to heat the air inside the kiln where timber is already stacked. The heated air is circulated through the timber stack using fans. This method has recently been introduced into substantial commercial use. There are many other methods of drying timber such as salt seasoning, solvent seasoning, boiling in oily liquids, vacuum drying, drying in superheated steam, vapour drying, press drying, radio frequency drying etc. None of these, however, are in general commercial use.

6.3.4 Preservative treatment

As timber is liable to attack by wood-destroying organisms, fungi, insects and marine borers, all timber used in structural work which is not of a naturally durable type is usually treated, using an appropriate preservative. Successful preservative treatment of timber depends upon the preservative chemical used, as well as the process by which it is applied to the timber. It is rarely possible to obtain complete impregnation of timber, the degree of penetration depending upon the species of timber, whether it is heartwood or sapwood and the treatment process. Complete penetration of the wood is not always necessary, provided that an outer layer of sufficient depth is impregnated. This layer must be of such thickness that any cracks or mechanical damage to the timber will not expose the inner untreated wood when the treated layer is broken in any way. When timber is cut or bored after being treated the newly exposed surfaces should be given a liberal application with a suitable preservative.

With the exception of diffusion treatment, the moisture content of the timber to be treated should not exceed 30 per cent. The maximum permissible moisture content depends to some extent upon the process, type of preservative and the kind of timber.

Wood preservatives may be divided into three main groups, namely tar oils, waterborne and organic solvents.

Tar-oil compounds or creosotes are resistant to leaching and hence suitable for exterior work, in water or in ground contact. They are not as a rule corrosive to metals. The principal advantages of creosotes are their high toxicity against fungi, insect and marine borers. Their disadvantages are that the treated timber has a strong odour and is difficult to paint. Tar- oil preservatives may be applied by vacuum-pressure, hot and cold open tank, brushes, spraying or immersion. For exterior work the recommended methods are either vacuum-pressure or hot and cold open tank.

Water-borne preservatives require special methods of application to ensure deep penetration and are not suitable for brush treatment. Drying the timber after treatment is necessary. The treated timber is odourless and can be painted over when it is dry. Water-borne preservatives based on a combination of copper, chrome and arsenic are applied to seasoned timber by vacuum- pressure methods, whilst boron compounds are applied to green timber by diffusion. They can be used in wet and dry conditions, including ground contact.

Organic solvent preservatives are readily absorbed by the timber and so may be applied by brush, spray or immersion. For a deeper penetration, methods such as double vacuum may be used. They do not cause the timber to swell. Treated timber may be painted and is not corrosive to metals.

Methods of treatment

The method used in applying a preservative is as important as its chemical composition and there are two main techniques, pressure and non-pressure methods.

Tar oil preservatives such as creosote are applied by pressure treatment, hot and cold tank methods, and also by immersion and brushing. Waterborne chemicals are normally used in pressure treatment and diffusion processes, whilst organic solvents are used in double vacuum or other non-pressure methods.

Brushing and spraying are the simplest methods of applying wood preservative. There are always the risks of incomplete coverage and of not allowing the timber to take up as much liquid as it would if completely immersed. Therefore, the preservative should be applied liberally, allowing the timber to absorb as much as possible, particularly in the areas of end grain, splits and joints. A certain amount of protection can be expected from this method but is slight compared with that of other methods. For timber which is fully exposed, it is of little value.

Immersion simply involves dipping the timber in a tank of preservative. The method is a little better than brushing and spraying because all surfaces of the timber can absorb liquid freely. The method is often referred to as "dipping" when the timber is immersed for less than 10 minutes and "steeping" when it lasts for several hours or days. Even the more thorough forms of this treatment provide little protection to timber under severe conditions, since the preservative does not penetrate deeply enough.

Diffusion treatment can be applied only on green timber. The process is to apply a waterborne preservative, usually as a concentrated solution, to the surface of the timber and to store it close-piled (block-stacked) and wrapped in plastic sheeting. The chemicals normally used are either boron compounds or fluorine compounds and sometimes a combination of both. The process time required for diffusion is several weeks depending upon the species, thickness of the timber and its moisture content at the time of treatment.

In the *hot and cold open tank* method, timber is immersed in cold preservative which is then heated to about 85 to 95 o C, and maintained at this temperature for an hour or more. The preservative is then allowed to cool down before the wood is removed. It is important that the timber is kept completely submerged during the whole process, which normally takes several hours. The temperature and the time can be varied to some extent, depending upon the species and the size of the timber. Any preservative that remains stable when heated may be used with the hot and cold open tank process, and in most cases creosote is used. The open tank process is a simple method of obtaining a good level of treatment.

In *sap displacement methods*, the sap in freshly-felled timber is displaced with an aqueous solution of preservative. The method can only be applied to green poles and posts.

In the *Boucherie* method, freshly cut unpeeled poles or posts are placed on the ground with butt ends slightly elevated. Watertight caps are fitted into the butt end and these caps are connected to a container at a higher level (normally about 10 m high). The container holds a waterborne preservative and it takes several days to penetrate the sapwood completely with little or no penetration of the heartwood. A variation of this is the Gewecke process which employs suction at one end while applying hydrostatic pressure at the butt end.

Pressure impregnation methods are the most important and successful techniques for applying preservatives to timber. The procedure is to stack timber in a steel pressure vessel and to force chemicals into the timber under pressure. Pressure methods give deeper and more uniform penetration as well as higher retentions of preservative in the timber. Hence, they give more protection than the other methods. Although there are a number of different processes which involve pressure treatment, the essential layout of the plant and equipment is always similar. Pressure processes are mainly of two types, either full-cell or empty-cell treatments, depending upon how the application of vacuum and pressure is carried out.

The double vacuum method employs a cylinder in which the timber is enclosed. From this, an initial vacuum is drawn and held for a period of time before the cylinder is flooded with preservative liquid, normally an organic solvent. The vacuum is then released so that the pressure in the cylinder increases, normally to atmospheric pressure. The preservative liquid is forced into the wood at this stage. The timber may be left to soak for a period before the preservative is removed from the cylinder, and then a final vacuum is applied.

Selecting a method of treatment

Table 6.1 provides a guide on the selection of an appropriate method of treating the timber for different end uses. For detailed recommendations, relevant country standards or codes of practice should be consulted. Specifications and standards relating to wood preservation are given in section 6.4. Details of preservatives together with methods of application are given in FAO *Forestry Paper 76* (FAO, 1986).

Table 6.1. Methods of applying wood preservatives,
based on D.F. Purslow, BRE

	Suitable processes				
Usage	Pressure	Open tank	Double vacuum	Diffusion	Immersion
Sea or fresh water	*				
In contact with the ground	*	*			
Outside but not in ground contact:					
Unpainted	*	*	*		*
Painted	*		*	*	*
Interior timbers:					
High humidity heavy condensation	*		*	*	
Insect attack low risk of decay	*		*	*	*

Fire

Because fire resistance is frequently and misleadingly associated with non-combustibility the excellent potential of timber as a fire-resistant structural material is seldom appreciated. In a fully developed fire situation, structural timber exhibits remarkable fire resistance. Although the timber chars at a rate of 30 to 40 mm per hour, the low thermal conductivity of both the timber and the char protects the unburnt wood, and thereby retains most of its original strength.

It is possible to protect timber structures by the application of surface coatings of fire retardants. These increase fire resistance by delaying the onset of heating of the structural member. Intumescent coatings are usually proprietary products. Some delay the heat by only a few minutes, while others can delay the arrival of heat for several hours. Details of the above methods were discussed and documented in 1970 (Fire Research Station, 1970).

6.3.5 Timber joints

The use of sawn and round timber in a range of structural applications is governed, to a large extent, by the availability of suitable fastening systems or components which permit the joining of members in a reliable and efficient manner. During the last few decades, design criteria for the common timber fasteners such as nails, screws, bolts, shear plates and split rings have evolved and in recent times, data on pressed steel nail plates and metal support brackets of various types have been added.

One of the different ways of catergorizing fasteners is the system adopted in the Australian Standard AS 1649 and the American National Standard ASTM D176-77 which lists fasteners under the following headings:

(a) Nails and screws under withdrawal and lateral loads;

(b) Bolts and connectors requiring bolts for their use in three member assemblies: shear plates, split rings and dowel type joints,

(c) Nail plates and tooth plate connectors manufactured in a variety of thicknesses and with a range of tooth types;

(d) Light gauge metal brackets used as joist hangers and brackets used as ties and frame supports.

Nails

There are very many varieties of nail shapes and materials (see figure 6.1). Round, plain wire nails are by far the most commonly used fasteners for timber. These are available with corrosion-resistant coatings, usually zinc based. Hot dipped galvanizing gives protection superior to other methods of zinc application and has a rougher surface finish which improves resistance to withdrawal, as does a rust-pitted surface.

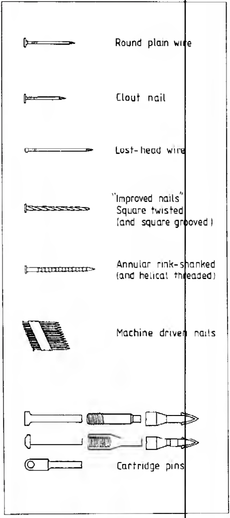


Figure 6.1. Nails for timber connections
Source: TRDA

Machine-driven nails are normally similar to round plain wire nails but the heads are shaped to allow magazine loading. Most nailing machines are pneumatically operated. Some of them, when equipped with specially hardened and tempered nails, will fix timber to hard materials like bricks and stone.

Improved nails, round or square, are available in most countries as bright, sherardised or untreated. These nails have the advantage of having higher permissible lateral and withdrawal loads.

Square twisted nails, designed originally for special uses, such as roofing, have proved to be excellent for attaching perforated metal plates. All the improved nails are good for attaching plywood gussets and for fixing sheet materials to floors where they resist "popping" - a problem which is often encountered with plain shank nails.

Cartridge pins have thick shafts compared with other nails. These are of many shapes for varied fixing requirements, including threads and eyes. The predominant uses are fixing to base materials of masonry and structural steel. All these nails are fully explained in the *Handbook of Fixings and Fastenings (Launchbury, 1971).*

An easy and effective means of jointing solid timber is by the use of plywood attached with nails or staples. Structural components, such as trussed rafters, plywood beams, ply gusseted plates and stud walls sheathed with plywood to provide wind- resisting shear walls, are some examples that exploit the advantages of nail or staple attachment.

Densely nailed plywood gussets enable high loads to be carried, for example in portal frame knee joints.

It is often thought that structural joints cannot be made in dense timber, such as greenheart, unless the holes are pre-drilled. In fact pre-drilling can usually be eliminated as extremely strong joints can be made by using plywood gussets nailed to the solid timber by small sized nails.

Screws

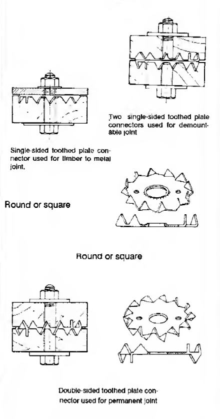
Screws are made out of as many materials as nails and a rather greater number of shapes and finishes, including plated decorative coatings. There are many types of screws including countersunk, round head, raised countersunk, Phillips and coach screws. The coach screws are much stronger and heavier than other screws. They are made of mild or galvanized steel and are used for outside work such as gate hinges and coach building. They are driven into the wood by means of a spanner.

Bolts

Bolts normally used in timber construction are made out of mild steel and are much stronger than nails. There are a number of factors which affect the strength of a bolted connection including timber species, bolt size and slenderness, width of members in the joints, number of shear planes, space requirements and quality control in fabrication. Launchbury (1971) gives details of bolts and bolted joints.

Timber connectors

Timber connectors used with bolts are toothed plates, split rings or shear plates. Toothed plate connectors may be double-sided or single-sided, as shown in figure 6.2.



Single-sided toothed plate connector used for timber to metal joint.

Two single-sided toothed plate connectors used for demountable joint

Round or square

Round or square

Double-sided toothed plate connector used for permanent joint

Figure 6.2 Toothed plate connectors
Source: TRADA

Single-sided toothed-plate connectors are used where load has to be transmitted from a timber member into a metal plate or gusset, where the load passes from the timber into the connector then via the bolt into the gusset. The single-sided connector is also used where prefabricated or easily demountable structures are required, each piece of timber having a connector embedded.

The double-sided toothed-plate connector is used where joints are permanent, being cheaper than two single-sided units. The connector is embedded in the contact surfaces simultaneously when the members are drawn together by the bolts passing through the connector and the timbers.

Split-ring connectors are so named because they are in fact rings which have a split (see figure 6.3). The function of the split is to accommodate timber shrinkage. Therefore, in the installation the grooves should be formed so that the connector is expanded when placed into the groove, sufficiently to prevent the ring completely closing when the timber has shrunk. They are assembled in a similar way to double-sided toothed-plate connectors, using bolts and transferring loads from member to member of a joint in the same way, but carry very much greater loads.

Shear-plate connectors are used in a similar way to single-sided toothed-plate connectors and have bolts assembled and loaded in the same way (see figure 6.3). They carry greater loads than tooth plates though not quite as great as the loads carried by split-ring connectors. As in the case of split-ring connectors, special cutting tools are required to cut the groove and the circular sinking. to accommodate the thickness of the connectors' centre plate, and a second sinking for the bolt of the larger connector.

Timber connectors of sheet material

Punched-metal plates (see figure 6.4) are only suitable for installation in a factory with special machinery, employed under controlled conditions, by fabricators who normally hold a manufacturer's licence for the use of a particular plate. The advantages lie in the formation of joints between members all in the same plane and rapid assembly line production of the structural components. Details can be obtained from the International Truss Plate Association, PO Box 44, Halesowen, West Midlands, United Kingdom.

Plain nail-plates (or nail on plates) (see figure 6.4) are not subject to the same proprietary restrictions as punched-metal plates and are intended for use out of the factory, needing only a hammer to make fabrication possible. The structural components for which they are used need not be dissimilar to those employing punched-metal plates.

Framing anchors are fabricated in most developed countries and in some developing countries in great variety. When such units are used in structural work it is necessary to choose one for which tests have established published load figures.

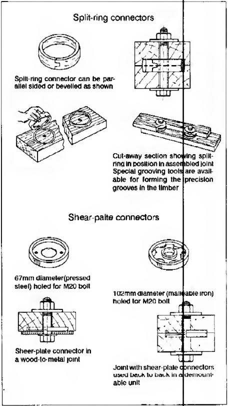
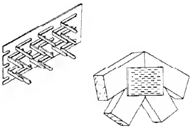

Split-ring connectors
Split-ring connector can be parallel sided or bevelled as shown
Cut-away section showing split-ring in position in assembled joint Special grooving tools are available for forming the precision grooves in the timber
Shear-palte connectors
67mm diameter(pressed steel) holed for M20 bolt
102mm diameter (malleable iron) holed for M20 bolt
Sheer-plate connector in a wood-to-metal joint
Joint with shear-plate connectors used back to back in a demountable unit

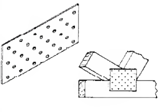
Figure 6.3. Timber shear connectors
Source: TRADA

Joist hangers are of many varieties. They may be thin pressed and/or folded sheet metal or thicker welded steel plate. Some are holed for nails or screws and some are not. Some are designed for hanging joist-ends to masonry and others to woodwork and steel, but these fixings are not normally available in developing countries. Where steel is available at an economic price these fixings should be considered in building construction.

End-joints are normally used in glued-laminated timber components. The three most common end-joints in



Punched-metal plate



Nail-plate or plywood gusset for hand nailing

Figure 6.4 Nail-on timber connector plates
Source: TRADA

commercial practice are the butt, finger and scarf joints. Out of these, the two most important are scarf joints and finger joints. Correctly fabricated scarf joints have a strength close to that of clear wood. However, in a rough factory environment, it is difficult to fabricate satisfactory scarf joints having a scarf slope of less than 1 in 10. Since ineffective scarf joints act like butt joints, they are not recommended for the fabrication of critical structural members.

6.3.6 Finishing processes

The type of finish applied to an article depends on the kind of timber that has been used and the purpose for which the finished article is intended. Timber exposed to the weather and unprotected by some kind of finish will 'weather' and quite rapidly become bleached and grey. Further weathering on prolonged exposure can lead to surface checking and splitting of the timber, and loss of wood fibre from the surface resulting in a woolly or corrugated appearance. It is inadvisable, therefore, to expose timber to the weather without the use of some form of protective treatment or finish. This is particularly the case where appearance is important.

It is important to realise, however, that the design of a building and its components can greatly influence the performance of the timber and its finish. The main design consideration is to minimize the absorption of water by the wood and to ensure drainage of water; the end grain at the bottom of external boards should be levelled; sills should be adequately levelled and throated; glued joints should be made with a suitably durable adhesive.There are four basic types of material which are suitable for the exterior treatment of wood: preservatives, paints, varnishes and exterior wood stains. Finishing processes are discussed in TRADA (1985), Collier (1967) and BRE Digest 261 (1974).

6.3.7 Manufactured products of wood

The range of wood-based products has grown dramatically during the last two or three decades. There have been many new wood- based products invented and, through technical innovation, modifications to existing products introduced since the World Consultation of Wood-Based Panels held at New Delhi in 1975 (FAO, 1975).

The additions to the three basic types of panels, plywood, particleboard and hardboard, are oriented strand board (OSB), medium density fibreboard (MDF), structural flakeboard and waferboards and composite panels as well as innovations within the conventional products.

Plywood

Plywood consists of thin layers of timber called veneers glued together. The layers, or plies, are glued with the grain directions perpendicular to each other. Plywood is made up from an odd number of veneers, the most commonly used being three-ply. Plywood is an ideal material for use as wall sheathing. As it is obtainable in large sheets, large areas can be covered quickly. It is easily fixed to wall battens without danger of splitting. Plywood can be used as flooring and its resistance to warping maintains a level surface. Special plywoods can be used for exterior work, and they should be of a grade known as WBP (weather and boil proof). Thinner plywoods can be used to form curved surfaces. Detailed information can be obtained from documents by the Standards Association of Australia

Collins (1985) suggests that in developing such a code visits should be made by architects and engineers to determine the size, shape and cost of houses in relation to the needs, lifestyles and aspirations of the local people. Good examples of light timber frame codes are available from Standards Association of Australia (1979c), Fiji Ministry of Forests (1985) and New Zealand Standards Association (1984).

6.5 Uses in construction

Timber as a construction material

For many centuries, timber was the structural material most widely used throughout the world because it was available and there were no alternatives in most applications.

In most developing countries where labour is freely available, the techniques used to produce a component must involve a high labour content. For example, joints occurring in the component should be nailed and not glued as the former can provide work for a large number of people as against the glued joints which require more skilled labour as well as more expensive equipment.

Principles of design

Whale (1986) states the following three considerations to be mainly responsible for the efficiency of wooden structures:

(a) The choice of structural form (for member components or complete buildings);

(b) The strength properties of the materials;

(c) The means of connection between members and parts (jointing techniques).

The preliminary choice of structural forms, which is generally undertaken by a structural design engineer and is largely a matter of intuition, experience and engineering judgement, will be followed by a systematic review of functional requirements before detailed design of individual components is undertaken.

During the past few decades considerable progress has been made in many countries in establishing standards of sizes and qualities for sawnwood and various wood-based panel products, often including stress grades based on the limitation of strength-reducing characteristics (such as knots, wane, slope of grain etc.). These standards will often relate to any of the design approaches listed earlier, and they are certainly a prerequisite for both analytical design or prototype testing.

Design stresses and methods of design are given in the following documents: British Standard BS 5268 (1985) and Standards Association of Australia Timber Engineering Code AS 1720 (1975).

Protection by design

The majority of problems of deterioration of structural timber are usually associated with excessive moisture or water in direct contact with the timber. At the planning stage, building orientation should be considered to reduce exposure of vulnerable components. When assembling and installing timber components care should be taken that water is not retained on surfaces nor enter the joints and that any water that does intrude can drain away. Shielding and structural detailing are two methods of providing physical protection for timber structures.

It is possible to have roof overhangs, shading devices and screen walls or fences to provide protection for the structural timber from sun and rain. Practical experience throughout the world has demonstrated the extremely valuable contribution made by shielding systems in prolonging the life of exposed building materials.

Detailing for durability of timber structures is discussed by Armstrong (1985a) in a paper prepared for UNIDO. In this paper, it is emphasised that when timber components are joined together or brought together into contact with other structural members or materials, care must be taken to avoid the entry of water and more importantly, to avoid trapping water in joints.

The most important protection problem for timber structure arises at the point of ground support. This area usually gets maximum exposure to the elements with minimum protection from the structure or surroundings. The best possible design solution is to isolate the timber structure from the ground. This will most usually be done with a steel shoe, steel plate, steel posts or bars or with a concrete base.

Although use of green timber in construction presents serious problems because of shrinkage, satisfactory structures of all types may be built of this material if due care is taken at the design and construction stages. It is necessary to visualize what is going to happen to a structure or to a joint when green timber shrinks and when required, make a simple provision for shrinkage. This is discussed in detail by Armstrong (1985b) and BRE Overseas Building Note No. 146 (1972).

Contruction practice

Construction practice is very important in the case of timber structures. Details of construction practice in addition to other information regarding timber are fully discussed in the UNIDO publications in the series *Timber Engineering for Developing Countries (UNIDO/10/606 to 610, 1985).*

Ollis (1973) suggests a way of classifying timber construction systems based on a broad correlation between uses and constructional forms and discusses the advantages and disadvantages of the individual types. Another useful guide is the *Popular Manual for Wooden House Construction (UNIDO, 1985).*

Timber for sheathing

Any timber sheathing, with the exception of naturally durable timber, can decay fairly rapidly if left unprotected. In most cases wood preservatives are not needed if the foundation sills (timber) are kept out of contact with the soil and the roof overhangs are adequate to keep water off the side walls. There are several types of sheathing to choose from.

The board and batten system consists of boards covered with battens where the boards are butted together. There are several variations of board and batten, including the reverse batten and board and the board and board. Batten and board puts the battens behind boards, and changes the appearance of the siding considerably. Board and board dispenses with the battens altogether.

Another type of vertical siding is shiplapped boards, which have a small half-lap on their edges, allowing the boards to overlap and shrink without creating an air gap.

A third method is the horizontal boarding sometimes called horizontal siding which is of several types. The most common are bevel siding, drop siding and shingles. Timber for external cladding is discussed in the document *Wood Information Sheet 20 by TRADA (1987).*

Timber for roof structure

Roofs in truss form using timber have been in existence for a long time. However, significant advances have been made in design and construction, especially with the use of bolts and other timber connectors at joints where previously mortise and tenon, half lap or straight nailed or pegged joints would have been used.

After the introduction of punched-metal connectors, trussed rafter design became popular in developed countries. However, trussed rafters are being manufactured in developing countries mostly using plywood gussets which are nailed to a defined pattern or nailed and glued to the truss members to form the joint.

Ply gussetted trusses offer a method of manufacture not requiring specialized equipment. Similarly, galvanized-steel plates punched with a pattern of holes to receive nails can also be used to form truss joints and these too can be fabricated on site. Trussed rafters are generally prefabricated in a factory and transported to site, although with certain types of plate, fabrication can take place on site. Mindfam (1986) discusses the use of timber in roof structures in detail.

Timber for roofing

Wooden shingles and shakes have been used both in developed and developing countries. Where timber suitable for the manufacture of shingles and shakes is available in appropriate sizes, these offer an advantageous solution for roofing. They are traditionally applied over open timber deck and roofing battens. It is important to pay attention to normal building practice, such as having a steep slope for the roof, the method of laying etc., since these are important for durability as well as for better performance. In addition, maintenance can increase the life span of shingles and shakes.

They may be applied over open spaced or solid sheathing. Solid sheathing may be of roofing sheets or roofing boards which are used especially in heavy rainfall areas. In the case of low- pitched roofs, particularly in heavy rainfall areas, it is necessary to have roofing sheets or timber roofing boards. For open spaced application, they are nailed to wooden battens which run the length of the roof. Round timbers of suitable size with a small flat cut on the top can be used as battens.

More details about shingles and shakes are given in Indian Standard (IS: 2700-1964) and *Shake and Shingle Manual (Papua New Guinea, 1976).*

6.6 Innovations in timber technology

There have been a few innovations during the last few years in both developed and developing countries. Among them the most important are solar drying, jointing methods, and the use of timber poles, bamboo, coconut wood and rubberwood.

Solar drying

After two decades of small-scale experimentation with solar timber drying design by many researchers in a number of countries, solar kilns are beginning to become accepted as a practical and economically viable method of drying timber. A schematic diagram is shown in figure 6.5. During the last few years they have been used commercially in fairly large numbers in the United States of America and in smaller numbers in India and in a few other tropical countries (Plumtre, 1985).

Rubberwood

Rubberwood which was earlier used mostly as firewood, has now become an excellent construction material. This is due to the application of proper preservatives at the correct time. Rubberwood is a non-durable timber and it is very prone to attack by a wide variety of insects and fungi. It is extremely important, therefore, to exercise proper care and treatment at every stage of processing. Lew Wing Hing (1983) recommends the following precautionary measures.

(a) Rubberwood logs must be sprayed with an anti-borer solution and properly end-coated if not processed immediately after felling. If proper end-coating and spraying treatment is done, it can give the logs an extended period of protection of up to four weeks.

(b) After the logs are converted to sawn timber, the sawn timber must be immediately dip-treated in an anti-stain and anti- borer solution. This treatment will prevent attack by sapstain fungi and borers. The recommended solution contains a mixture of 2 per cent by weight each of gamma BHC (26 per cent Wettable Powder), borax and sodium pentachloraphenate. The sawn timber must be dipped for at least two minutes in this solution. This treatment gives only temporary protection as the preservatives form a superficial protective layer on the wood.

(c) After the dip-treatment the sawn timber must be properly stacked under cover. The period of diffusion of the chemical into the timber varies with the thickness of the timber.

(d) After diffusion the timber can be either air dried or kiln dried.

Recent research work has opened up new options for using rubberwood besides solving some use problems. The properties of the timber have been much more thoroughly studied and possible uses for the manufacture of several wood-based products such as particle board, glue-laminated products and fibreboard have been discussed (Wong and Ong, 1979).

Further reading

British Standards Institution, BS 881 and 579: 1974, *Nomenclature of Commercial Timbers including Sources of Supply* (London, 1974).

Building Research Establishment, *Timber Drying Manual* (London, Her Majesty's Stationery Offices, 1985).

Food and Agriculture Organization of the United Nation, Forestry paper 76: *Wood Preservation Manual* (Rome, 1986).

———, *Proceedings of the World Consultation on Wood Based Panels in New Delhi, 1975.*

Lew Wing Hing, *Rubberwood, Malaysian Timber Marketing Conference, 6-7 December, 1983,* Malaysian Timber Industry Board, Malaysia.

Philippines Coconut Authority, *Coconut Wood, The Proceedings, Manila and Zamboanga, 22-27 October,1979.*

Plumtre, R.A., *Solar Drying Kilns for Sawnwood,* Forest Products Abstracts Review Article, vol. 8, No. 2 (Oxford, Commonwealth Forestry Bureau, 1985).

Standards Association of Australia, Australian Standard, AS 1649- 1974, *Determination of Basic Working Loads for Metal Fasteners for Timber* (Sydney, 1974).

Timber Research and Development Association, *Timber Stress Grading, Analysis of Existing Timber Strength Grouping and Srength Classification Systems,* paper 10/WG 447/2, UNIDO Expert Group Meeting on Timber Construction, Vienna, 1985.

United Nations Industrial Development Organization, *Timber Engineering for Developing Countries*, Part 1 and Part 5, document Nos. UNIDO/10.606, UNIDO/10.607, UNIDO/10.608, UNIDO/10.609 and UNIDO/10.610. (Vienna, 1985).

United States Department of Agriculture, *Wood Handbook,* USDA Agriculture Handbook No. 72 (Washington, D.C., 1974).

Equipment manufacturers and suppliers

AUSTRALIA

Kockums
P.O. Box 32
Welland
Adelaide
Sawmilling machinery

Leitch Timber Services
14 Poina Street
Park Beach
Tasmania
Woodworking machinery

Weing Australia Pty Limited
37 Justin Street
Smithfield
NSW 2164
Woodworking machinery

BRAZIL

Invicta Maquinas Para Madeira Ltda
Av Major Jose Levy Sobrinho
No 2500-CEP 13 480
Limeira
Sao Paulo
Woodworking machinery

Montana Quimica S A
P O Box 7340
Rue Ferreira Viama
Sao Paulo
Timber treatment and preservative chemicals

CANADA

Cae Machinery Limited
3550 Lougheed Highway
Vancouver
British Columbia V5M 2A3
Timber drying kilns

Kockmus Cancar Inc
19433 96th Avenue
Surrey
British Columbia
Woodworking machinery

GERMANY, FEDERAL REPUBLIC OF

Babcock-BSH
P O Box 266
D-6430 Bad Hersfield
Timber drying equipment

Hilderbrand Holztechnik GmbH
P O Box 1860
D-7440 Nuertingen
Timber drying equipment

Interholz Raimann GmbH
Weisserlenstrasse 11
D-7800 Freiburg
Woodworking machinery

Kusters, Eduard Maschinenfabrik GmbH and Co KG
Postfach 1750
Gladbacher Strasse 457
D 4150 Krefeld
Woodworking tools (electric)

INDIA

Ascu India Limited
7A Elgin Road
Calcutta - 700020
Timber treatment plants and preservative chemicals

INDONESIA

Basuki Pratama Engineering PT
Jalan Raya Bekasi
KM 18 No 25
Jakarta 13930
Timber drying kilns

Euroasiatic Jaya PT
Jalan Hayam Wuruk 95
Jakarta 11160
Timber drying kilns

ITALY

Balestrini Renzo SpA
Via Don Sturzo 3
1-20030 Seveso
Woodworking machinery

Coppa srl
Via Don Sturzo scn
1-20031 Cesai
Maderna M1
Timber drying kilns

Pagnoni Impianti SpaA
Via Sempione 31
1-20052 Monza M1
Woodworking - hand tools

SOGEMAC SRL
2v del Lavoro
47083 S. Arcangelo
Sawmilling and woodworking machinery

JAPAN

Chubu Machinery Mig Co Limited
14-2 Chuo-cho
Shimada City
Shizuoka Prefecture
Electric and hand tools

Kikukawa Iron Works Inc
85 Ominato-cho
Ise City
Mie Prefecture
Woodworking machinery

Mitsutomi Co Limited
6-Chome 5-49 Toro
Shizuoka 422
Equipment for glued laminated timber

MALAYSIA

Hickson Timber Preservation (M) Sdn Bhd
208 Renong Westcourt
126 Jalan Klang Lama
58000 Kuala Lumpur
Timber treatment plants and chemicals

Sawell Machine Knives Sdn Bhd
Lot 14981
Sub Lot 7-11
7th Mile
Jalan Puchong
Kuala Lumpur
Sharpening tools for woodworking and sawmilling machinery

SINGAPORE

Ciba-Geigy SE Asia (Pte) Limited
No 4 Fourth Lok Yang Road
Singapore 2262
Wood glues

Hildebrand Singapore Pte Limited
10 Anson Road No 30-15
International Plaza
Singapore 2600
Timber drying equipment

Homag Services Singapore (Pte) Limited
896 Dunearn Road
No. 01-03 Sime Darby Centre
Singapore 2158
Woodworking tools

MacQuip (SEA) Pte Limited
Farrer Road
P O Box 2
Singapore 9128
Sawmilling machinery

SPAIN

Barneran SA
P O Box 160
Castelldefels
Barcelona
Equipment for manufacture of glued laminated timber

SWITZERLAND

Fischer, George Limited
Wildischachen
CH-5200 Brügg
Equipment for glued laminated timber

UNITED KINGDOM

Cambridge Glass House Co Limited
Comberton
Cambridge CB3 7BY
Solar timber drying kilns

Ciba-Geigy Plastics
Duxford
Cambridge CB2 4QA
Wood glues

Forestor Saw Mills and Equipment Engineering Limited
2 Bloss Wood Lane
Whitchurch
Hants RG28 7AX
Sawmilling machinery

Fosroc Limited
Fieldhouse Lane
Marlow
Bucks
Timber treatment plants and preservative chemicals

Rentokil Limited
Felcourt
East Grinstead
West Sussex R19 2JY
Timber treatment plants and preservative chemicals

Rye Machinery Limited
Lincoln Road
High Wycombe HP12 3TR
Furniture manufacturing plants

Stenner of Tiverton Limited
Lowman Green
Tiverton
Devon EX16 4JX
Woodworking machinery and sharpening equipment

Thomas Robinson and Son Plc
Railway Works
Rochdale
Lancashire OL16 5NB
Woodworking machinery

Wadkin Plc
Green Lane Works
Leicester LE5 4PF
Woodworking machinery

Wood Power Tools Limited
Hanger Lane
London W5 1DS
Woodworking tools (electric)

UNITED STATES OF AMERICA

Armstrong Manufacturing Co
P O Box 3008
2135 N W 21st Avenue
Portland
Oregon 97208
Woodworking machinery

International Sharpening Machines Inc
7597 Charmant Drive
Suite 910
San Diego
California 92122
Sharpening machines for sawmilling and woodworking machinery

Koppers Inc
Pittsburgh
Pennsylvania 15219
Timber preservation plants and preservative chemicals

Chapter 7

Technology transfer and adaptation

Introduction

An important aim of this compendium is to foster international and inter-organizational communication and links, so-called technology transfer, to promote the development of low cost building materials. This has been done in three ways. First, by means of an extensive reference list at the end of the compendium, where the sources of the work referred to in each chapter are given; secondly, through the lists of equipment suppliers which are located at the end of each chapter; and thirdly, by the identification of other organizations worldwide which are involved in the process of technology transfer and adaptation; these latter organizations are listed in this final chapter.

The lists of equipment suppliers given at the end of each chapter will help to identify some established firms which can supply the machinery and equipment for particular technologies. Many but by no means all of these are in the industrialized countries, and it is worth mentioning that firms in the industrialized countries are not necessarily the best equipped to supply the needs of the small-scale building materials manufacturer in the developing countries. Their markets tend to be predominantly in the industrialized countries where large output enterprises with high wage rates predominate, and the equipment they supply is thus often designed for labour-saving, high-volume output. An attempt has been made in listing equipment manufacturers in the industrialized countries to identify those which are concerned to some extent with smaller scales of production. The manufacturers located in the developing countries will often be found to have undertaken development work to adapt the technology concerned to the needs of the smaller-scale, more labour-intensive enterprise. The lime kiln suppliers in India and the soil-block presses made in Guatemala and Peru are examples. Prices of equipment made in a developing country also tend to be lower.

The intention of promoting communication and technology transfer is not limited however to commercial import of machinery and equipment. The technology of low-cost building materials, as will be realised from the preceding technical chapters, is a rapidly developing field, and many of the most promising innovations are those which have not yet reached the stage of commercial marketability, or, frequently, are designed precisely to avoid the need for commercially purchased equipment. In India, the Khadi and Village Industries Commission has carried out a nationwide programme of developing small-scale village lime industries using a kiln design which is fabricated with local materials with some assistance from local workshops. Action-Aid has used a similar approach in developing the use of fibre- concrete tiles in Kenya. Organizations such as these, principally involved in field projects for the application of particular technologies, are referred to here as development and application organizations. Section 7.2 lists 36 such organizations, with notes on the activities of each.

In other cases, promising new technologies have been developed in research organizations, some of which are university based, but which also include many national research laboratories. Often these organizations, though not primarily development organizations, have been involved in field trials or demonstration projects, though the technologies may not have been developed to the point of commercial application. The Central Building Research Institute in India has developed highly efficient designs for continuous brick kilns which can be made entirely from materials which are available locally, with assistance from local workshops; the Building and Road Research Institute at the University of Kumasi in Ghana has developed a block press which can be manufactured locally, and so on. Many of these research organizations provide documentation, information packages and run training courses on specific building materials technologies. A total of 76 such research and training organizations are listed in section 7.1, with notes on their activities.

Finally, the chapter lists the principal international organizations which are involved in either technical assistance, documentation or other means of promoting the development and use of low-cost building materials. The term is used here for those organizations set up by the United Nations or some other inter- governmental collaboration. It is realised that many of the development and application organizations listed in section 7.2 are also, in terms of their operations, international organizations. Nine such organizations are listed in section 7.3, again with notes on their activities.

In conclusion it should be noted that these lists are by no means complete, and no guarantee can be given of the accuracy of addresses or other information presented. They contain the best information available to UNCHS (Habitat) and its consultants at the time of preparation of this report. It is hoped to maintain and develop this database. Comments, corrections and additional information for this purpose is welcome.

7.1 Research and training organizations

ALGERIA

Centre national d'etudes et de recherches integrees du batiment (CNERIB)
Cite Nouvelle El Mokrani
Wilaya de Tipaza
Souidania
National research and documentation centre.
Founded: 1978.
Research and documentation on low-cost building materials and low cost binders

ARGENTINA

Asociación Técnica Argentina de Ceramica
Talcahuano 847
Buenos Aires
National research association
Research and documentation on brickmaking

Centro de Investigación Tecnología de la Madera y Afines (CITEMA)
Juana M. Gorriti 3520
C C 42
1708 Moron
Research organization
Research and development in timber drying, preservation and construction

AUSTRALIA

Council for Scientific and Industrial Research Organization (CSIRO)
P.O. Box 56
Graham Road
Highett
Victoria 3190
Research organization: information and documentation: technical co-operation
Research in timber utilization; building materials durability; life cycle performance

University of New South Wales
P.O. Box 1
Kensington
NSW 2033
University research centre
Research on low-cost binders; rice-husk ash cements

Wood Technology and Forestry Research Station
Oratava Avenue
Wast Pennant Hills
P.O. Box 100
Beecroft
NSW 2119
Research organization
Founded: 1936
Research in conversion of wood, wood structure, drying, preservation and timber engineering
Research projects in China

BANGLADESH

Housing and Building Research Institute
Darus-Salam
P.O. Box 2953
Mirpur
Dacca 18
Government research organization
Founded: 1977
Research on low-cost construction; soil construction stabilized-soil bricks; fired-clay bricks; phospho-gypsum building products

BELGIUM

Post Graduate Centre for Human Settlements
Katholeike University Leuven
Kasteel Arenberg
B3030 Heverlee
University research and training centre
Extensive research programmes on soil construction; low-cost
binders, rural housing technology

CHINA

Building Materials Research Institute
19 Hsiang Tung Road,
Fu Chen Gate
Beijing
Government research organization

EGYPT

General Organisation for Housing Building and Planning Research
P.O. Box 1170
El Tahreer St
Dokky
Cairo
Government research organization
Research on fired-clay bricks; low-cost binders; blended cement; soil construction

ETHIOPIA

Faculty of Technology
Addis Ababa University
P.O. Box 518
Addis Ababa
University research centre
Research on soil construction; local timber utilization; clay bricks and tiles; blended cements

Wood Utilization and Research Centre (WUAR)
P.O. Box 2322
Addis Ababa
Research organization
Research in timber properties, seasoning and preservation

FRANCE

Centre expérimental du bâtiment et des travaux publics
12 rue Brancion
75737 Paris 4
Government research centre

Centre scientifique et technique du bâtiment (CSTB)
24 rue Joseph Fourier
38400 St Martin D'Heres
Government research and documentation organization
Founded: 1947
Research and documentation covering entire field of building materials; publication of MTEC '86 conference proceedings on low-cost building materials

Centre technique des tuiles et briques
2 avenue Hoche
75008 Paris
National research association
Research and documentation on brickmaking

Centre technique forestier tropical (CTFT)
45 bis, avenue de la Belle Gabrielle
F-94130 Nogent-Sur-Marne
Research organization: professional training with tuition: information and documentation; technical co-operation
Founded: 1948
Extensive research In tropical timber specially in francophone developing countries

Syndicat national des industries du plâtre
3 rue Alfred Roll
75017 Paris
Industry research and documentation organization
Research and documentation on gypsum plaster manufacture

GERMANY, FEDERAL REPUBLIC OF

Fraumhofer-Institüt für Holzforschung
Bienroder Weg 54E
D-3300 Braunschweig
Research organization
Applied research in timber and timber based products
Field projects in Chile, China, Philippines

Institut für Tropenbau
Waldschmidtstr 6a
D-8130 Starnberg
University research centre
Research and publications on low-cost building materials; study of soil block press

GHANA

Building and Road Research Institute
University of Science and Technology
P.O. Box 40
Kumasi
Government funded research centre
Research and documentation on burnt-clay bricks and tiles; soil construction; low-cost binders; use of mine-waste pozzolanas
Training courses in brick manufacture

GUATEMALA

Centro de Investigaciones de Ingenieria
Ciudad Universitaria
Zona 12
Guatemala, C.A.
University research centre
Research on soil construction, adobe blocks; soil stabilization; rammed-earth walls; development of CETA-ram press

INDIA

Birla Institute of Technology
Misra
8352
15 Ranchi
Bihar
University research centre
Research on low-cost binders

Cement Research Institute
M-10 South Extension 11
Ring Road
New Delhi 110049
Independent research organization
Research on cement utilization; mini-cement plants; rice-husk ash cement

Centre for Application of Science and Technology to Rural Areas (ASTRA)
Indian Institute of Technology
Bangalore 560012
University-based research and development centre
Research on soil-stabilized development of ASTRAM block-making machine

Central Building Research Institute
Roorkee 247667
Government research organization
Founded: 1947
Research and process development in low-cost building materials; burnt-clay brick and tile manufacture; soil construction; lime kilns, lime hydration; lime-pozzolana binders, manufacture and use

Development Alternatives
22 Palam Maarg
Vasant Vihar
New Delhi 110057
Independent voluntary organization
Research and dissemination of appropriate technologies; research on fibre concrete roofing

Indian Institute of Technology
Department of Metallurgical Engineering
Kanpur 208016
University research centre
Research on low-cost binders; development of ASHMOH and ASHMENT rice-husk ash cement processes

Indian Plywood Research Institute
Tumkur Road
Post Bag 2273
Bangalore 560022
Karnataka
Government sponsored co-operative research organization: professional training centre, information and documentation; technical co-operation
Research and development in plywood and other wood-based panel products

Regional Research Laboratory
Jorhat 785006
Assam
Government research institute
Research on small-scale cement manufacture

Structural Engineering Research Centre (SERC)
CSIR Campus
Madras 600011
Government research organization
Research on low-cost construction techniques; soil construction; development of latoblock lime-stabilized blockmaking process

Timber Mechanics Section
Forest Research Institute
P.O. New Forest
Dehra Dun
Uttar Pradesh
Government research organization: professional training institute; technical co-operation
Research and development saw milling, drying preservation and timber structure

INDONESIA

Directorate of Building Research
Jalan Tamansari 84
P.O. Box 15
Bandung
Government research organization
Founded: 1953
Research on low-cost binders; volcanic-ash pozzolana; lime- pozzolana blocks
Training courses in building materials development

IRAQ

Building Research Centre
Jadriya
P.O. Box 127
Baghdad
Government research centre
Research into pozzolanic cements; blended cements; gypsum plaster; fired-clay bricks

JAMAICA

Building Research Institute
34 Old Hope Road
P.O. Box 505
Kingston 5
Government research organization
Research on soil stabilization

JAPAN

Department of Forest Products Science
Faculty of Agriculture
Isizuoka University
Kio, Ohya
Isizouka-shi
Shizuoka
University research organization: technical co-operation
Founded: 1966
Wood technology and wood processing
Co-operates with developing countries in staff training

KENYA

Housing Research and Development Unit (HRDU)
Department of Architecture
University of Nairobi
P.O. Box 30197
Nairobi
University research organization
Founded: 1967
Studies of stabilized-soil blockmaking with CINVA ram, BREPAK and local machines, and soil assessment; development of hand-operated fibre concrete tile vibrating unit

MALAYSIA

Standard and Industrial Research Institute of Malaysia (SIRIM)
P.O. Box 35
Shah Alam
Selangor
Government research and standards institute
Research on burnt-clay bricks; rice-husk ash cement

MEXICO

Escuela de Ingenieros en Tecnología de la Madera
División de Ciencias Ingeniería
Universidad Michoacana de San Nicolas de Hidalgo
Edificio A, planta baja
Ciudad Universitaria
58030 Morelia, Michoacán
University research centre
Founded: 1973
Development work in timber industries

NEPAL

Research Centre for Applied Science and Technology
Tribhuvan University
Kirtipur
Kathmandu
University research centre

NETHERLANDS

BIE Institute for Housing Studies
Weena 718
P.O. Box 20718
3001 JA Rotterdam
Independent research and training institute
International training courses on housing

Centre for International Co-operation and Appropriate Technology
Delft University of Technology
P.O. Box 5048
2500 GA Delft
University research centre
Research on soil construction, stabilized-soil blocks; local timber utilization; development of wire lacing tool

Stevin Laboratorium Voor Toegepaste Mechanica Constructies en Materialen
Stevinweg 1
P.O. Box 5048
DK-2600 Delft
University research laboratory: information and documentation; technical co-operation
Founded: 1955
Use of wood and wood products in building

NIGERIA

Nigerian Building and Road Research Institute
15 Awolowo Road, Ikoyi
P.O. Box 12568
Lagos
Government research institute
Research on soil construction; burnt-clay bricks and tiles

NORWAY

Norsk Treteknisk Institutt
Forskningsveien 3B
P.O. Box 337
Blindern
N-0314 0510 3
Independent research institute
Founded: 1949
Sawmilling, timber structures, preservation and chipboard
Field project in Zimbabwe

PAKISTAN

Building Research Station
University of the Punjab
New Campus
Lahore 20
University research centre
Research on gypsum utilization

PCSIR Laboratories
Jamrud Road
P.O. Peshawar University
Peshawar
Government research institute
Research on low-cost binders: rice-husk ash cements

Earth Resources Technology Centre
Wilseyville
California
Independent research and construction centre
Development of rammed-earth walling system
Publications on rammed earth walling techniques

International Foundation for Earth Construction
2501 M St N.W. Suite 450
Washington D.C., 20037
Independent research and documentation organization
Soil construction; stabilization with asphalt

International Institute of Housing Technology
Fresno State College
California
University research organization; training centre
Development of processes for adobe block manufacture; asphalt stabilization; publication of manual

Rammed Earth International Institute
2319 21st Avenue
Greeley
Colorado 80631
Independent research and documentation organization
Research and publications on rammed-earth wall construction

University of California, Berkeley
Department of Civil Engineering
Berkeley
California 64720
University research centre
Research on low-cost binders, rice-husk ash cements

VIET NAM

Institute for Building Science and Technology
Ministry of Construction
Hanoi
Government research institute
Research on low cost binders; lime manufacture; clay bricks and tiles; soil stabilization

ZAMBIA

National Council for Scientific Research
P.O. Box CH158
Chelston
Lusaka
Government research centre
Founded: 1970
Research into manufacture and use of stabilized-soil blocks

University of Zambia at Ndola
P.O. Box 21692
Kitwe
University research centre
Research on burnt-clay brick production; use of agricultural waste fuel

7.2 Development and application organizations

AUSTRALIA

South Australian Timber Corporation (SATCO)
135 Waymouth Street
P O Box 1604
Adelaide
SA 5001
Development institute: information and documentation
Founded: 1979
Development work in sawmilling, plymilling and timber construction

BELGIUM

COOPIBO
Naamsesteenweg 573
B 3030 Heverlee
Leuven
Independent development co-operation organization
Development of PPCT binder project in Rwanda; research on lime kilns, volcanic-ash pozzolana

BOTSWANA

Southern Rural Development Association (SRDA)
Kanye
Government rural development agency
Founded: 1979.
Establishment of production units in low-cost building materials; fired-clay bricks; low-cost binders; development of blended cement production technology

BRAZIL

Centro de Pesquisa de Produtos Florestais Estrado do Aleixo
1756 C P 478 69.000 Manaus
Amazonia
Development institute
Founded: 1978
Development work in sawn timber, board products, drying, preservation and timber engineering

BURKINA FASO

Association pour le développement naturel d'une architecture et d'un urbanisme africain (ADAUA)
Avenue d'Oubritenga
P.O. Box 648
Ougadougou
Research organization; information and documentation
Founded: 1978
Field projects in use of soil in construction in many community architecture projects in African countries

CANADA

Forintek Canada Corporation
6620 N W Marine Drive
Vancouver BC
V6T 1XZ
Development institution: technical co-operation
Founded: 1927
Research and development in sawmilling, composite products, preservation and timber engineering
Plans to strengthen its research links with developing countries

CHINA

China National New Building Materials Corporation
Zi Zhu Yuan Road/XI Jiao
P.O. Box 2815
Beijing
Government research and technical co-operation agency
Founded: 1980
Research documentation and technology transfer in entire field of building materials

COLOMBIA

Servivienda
Calle 48, No. 14-61
Apartado 51681
Bogotá
Independent housing improvement agency
Research on rice husk cement; soil blocks; establishment of CCA cement plants

DENMARK

Department of Wood Technology
Teknologisk Institute
PO Box 141
Gregersenvej 3
DK 2630, Tastrup
Research organization; technical co-operation
Founded: 1906
Research into timber and timber-based materials, timber processing and timber engineering

ECUADOR

CATER (Centro Andino de Tecnologiá Rural)
Casilla 399
Loja
University-based rural development and technicel assistence egency
Founded: 1980
Studies of rural housing within mainly agricultural projects
Centro Sinchaguasin
Apartado 471
Latacunga
Cotopaxi
Independent rural development organization
Development of low-cost housing techniques for Ecuadorian highlands; rammed-earth walling construction; improved limewash for earth walls; reconstruction after 1987 earthquake

FIJI

Utilization Division
Department of Forestry
Ministry of Forests
P.O. Box 2218
Suva
Government department
Development work in sawmilling, seasoning and preservation

FRANCE

CRATERRE
Centre Simone Signoret
B.P. 53
38090 Villefontaine
Research organization; professional training institution; information and documentation; technical co-operation
Founded: 1979
Extensive research into earth-building technologies in francophone Africa and South America

Development Workshop
B.P.10
Montayral
47500 Fumel
Research organization; information and documentation; technical co-operation
Founded: 1971
Field projects developing and using soil construction and other low-cost techniques in numerous countries

Groupe des recherches et études technologiques (GRET)
213 rue Lafayette
75010 Paris
Research organization; information and documentation; technical co-operation
Founded: 1976
Field projects in mainly African countries; extensive documentetion on traditional technologies in French; manuals on aspects of soil construction; lime; gypsum; burnt bricks and tiles

Ministère de l'urbanisme, du logement et des transports - Plan construction et habitat (REXCOOP)
1, rue François Premier
75008 Paris
Government technical co-operation agency
Founded: 1971
Field projects in many countries incorporating innovations in low-cost building materials; low-cost binders; soil construction; gypsum plaster; fired-clay bricks and tiles; research sponsorship

GERMANY, FEDERAL REPUBLIC OF

GATE
Postfach 5180
D-6236, Eschborn-1
Government research, documentation and technical co-operation agency
Founded: 1978
Field projects involving innovations in low-cost building materials; documentation in soil construction; pressed soil blocks; low-cost binders; lime-pozzolana binders; fibre concrete roofing

GUATEMALA

CEMAT
18, Calle 22-25
Zona 10
Apartado Postal 1160
Guatemala City
Independent appropriate technology organization
Field projects in use of lime-pozzolana binders; block manufacture from volcanic-ash pozzolana

Universidad de San Carlos, Facultad de Arquitectura
Centro de Investigaciones (CIFAR)
Ciudad Universitaria,
Zona 12
Guatemala City
Research organization
Founded: 1980
Development of CETA ram block press

INDIA

Appropriate Technology Development Organisation (ATDO)
P.O.Box 311
Gandhi Bhawan
Lucknow 226001
Independent technology development and application organization
Development of 25 ton/day mini-cement plant

Khadi and Village Industries Commission
Gramodaya
3 Irla Road
Vile Parle (West)
Bombay 400056
Rural development technology development and transfer organization Development of lime kilns; lime-pozzolana binders; LYMPO process
Training courses in construction and operation of lime kilns and lime-pozzolana manufacture

Village Reconstruction Organization (VRO)
By pass road
Pedakakani, P.O. Box 522509
Guntur
Andhra Pradesh
Independent rural development agency
Village reconstruction projects in India incorporating innovations in low-cost building materials; rice-husk ash cement

INDONESIA

Ceramic Research and Development Association
Jalan Jenderal Akhmad Yani, 392
Bandung 40272
Government research and development institute
Development activities in lime-kiln designs; process for clay bricks and roof tile manufacture

KENYA

Action-Aid Kenya
P.O.Box 42814
Nairobi
NGO; rural development organization
Development in use of local materials; publication of manuals on sun-dried bricks, stabilized-soil blocks; burnt clay bricks; fibre concrete roofing

MALAYSIA

ASEAN Timber Technology Centre
PO Box 10887
Kuala Lumpur
Research and development organization; information and documentation, technical co-operation
Field projects in member countries of ASEAN

PAKISTAN

Appropriate Technology Development Organisation (ATDO)
1A/B, 47 St
F-7/1 Islamabad
Government technology transfer agency
Field projects in establishment of rice-husk ash cement technology

PERU

CRATERRE
Apartado Postal 5603
Lima
Research organization; community development and technical co-operation
Studies of traditional soil building processes; development of CRATERRE press, and formwork for rammed earth construction; publications on earth building

ININVI
Panamericana Norte 16900
P.O.Box 31-056
Lima
Government research and technology development agency
Research and demonstration projects in soil construction, low- cost binders, local timber utilization

RWANDA

COOPIBO/PPCT
B.P.31
Ruhengeri
Independent development agency concentrating on low-cost building materials.
Development of LIPORWA low-cost binder production technology; investigations of brick and tile technologies; use of local timber

SWITZERLAND

SKAT
Varnbueelstrasse 14
CH-900
St Gallen
Independent technology transfer and documentation organization
Studies and documentation on low-cost building materials, especially FCR; convenor of FC Advisory Service

UNITED KINGDOM

Intermediate Technology Development Group (ITDG)
Myson House
Railway Terrace,
Rugby CV21 3HT
Independent technology development and transfer agency
Founded: 1971
Programmes of technology transfer and documentation in burnt-clay bricks and tiles; low-cost binders; soil construction; fibre- concrete roofing
Extensive publications across whole field of low-cost building materials

Parry Associates
Overend Road
Cradley Heath
West Midlands B64 7DD
Independent consultancy concentrating on technology development and transfer in building materials
Development of fibre concrete roofing production processes; equipment for small-scale brick and tile manufacture and block making; training courses in fibre concrete roofing

TERRE
109 High St
Portsmouth
Hants PO1 2HJ
Independent consultancy
Specialization in raw materials assessment for clay products, lime and low-cost binders

UNITED REPUBLIC OF TANZANIA

Small Industry Development Corporation
P.O. Box 2476
Dar es Salaam
Government technology transfer and development agency
Development of lime and lime-pozzolana production telchnologies; training programmes in lime production

UNITED STATES OF AMERICA

Appropriate Technology International
1331 H St N.W.
Washington D.C., 20005
Independent development and technology tranfer organization
Projects, studies and documentation on fibre-concrete roofing, low-cost binders and other low-cost building materials

Volunteers in Technical Assistance (VITA)
1815, Lynn St
Rosslyn
Virginia 22209
Independent development and technology transfer organization
Technical assistance and documentation on lime manufacture, stabilized soil block manufacture; burnt-clay brick manufacture

7.3 International organizations

AUSTRIA

United Nations Industrial Development Organization
P.O.Box 400
Vienna International Centre
A-1400 Vienna
United Nations technical assistance and documentation agency
Founded: 1967
Technical assistance and documentation in low-cost building materials production processes; burnt-clay bricks and tiles, pressed-soil blocks; lime; low-cost binders

FRANCE

International Union of Testing and Research Laboratories for Materials and Structures (RILEM)
12, rue Brancion
75737 Paris Cedex 15
International agency concerned with building materials standards and testing
Founded: 1947
Research and documentation across entire range of building materials

INDIA

Asian and Pacific Regional Centre for Transfer of Technology
ESCAP
49, Palace Road
P.O. Box 115
Bangalore 560052
International technology transfer organization; promotion transfer and utilization of commercially proven technologies

National Buildings Organisation and United Nations Regional
Centre
Nirman Bhawan, G Wing
Maulana Azad Road
New Delhi 110011
National and international building technology development, transfer and documentation organization
Development activities in gypsum, lime, lime-pozzolana binders, brick manufacture

KENYA

United Nations Centre for Human Settlements (Habitat)
P.O.Box 30030
Nairobi
United Nations technical assistance and documentation agency
Technical assistance and documentation in low-cost building materials; soil construction; low-cost binders; bricks and tiles; fibre concrete roofing; timber

NETHERLANDS

International Council for Building Research, Studies and Documentation (CIB)
Weena 704
P.O.Box 20704
3001 JA Rotterdam
International building documentation agency
Founded: 1953
Publications and conferences across entire range of building materials

SWITZERLAND

ILO Technology and Employment Branch
CH-1211 Geneva 22
United Nations technical assistance and documentation agency
Founded: 1919
Publication on small-scale brick-making; pressed-soil block manufacture

THAILAND

United Nations Economic and Social Commission for Asia and the Pacific
Division of Industry, Human Settlements and Technology
Rajadamnern Avenue
The United Nations Building
Bangkok 10200
United Nations documentation agency
Founded: 1949
Documentation on all aspects of low-cost materials

UNITED KINGDOM

Commonwealth Science Council
Marlborough House
Pall Mall
London SW1Y 5HX
International technical co-operation agency
Founded: 1965
Collaborative research programme on local raw materials for construction with African countries

BIBLIOGRAPHY

Abbas, Z.A. (1977). The Development of Building Materials for Housing in Indonesia. Directorate of Building Research, Bandung, Indonesia.

Action-Aid (1985). Roofing with Fibre-Cement Tiles. Unpublished report. Action-Aid, Kenya.

Action-Aid (1986). Better Burnt Bricks. Action-Aid, Kenya.

Action-Aid (undated). Moulding and Building with Sun-dried Bricks. Action-Aid, Kenya.

Aggarwal, A. (1981). Mud, Mud. Earthscan Publications.

Agopyan, V. (undated). GRG Prepared by Premixing for Wall Panels in Developing Countries. Instituto de Pesquisas Tecnologicas do Estado de Sao Paulo, Sao Paulo.

Akinmusuru, J.O. (1984). Lateritic soil-cement bricks for rural housing. International Journal of Cement Composites and Lightweight Concrete, vol. 6, No. 3.

Allen, W.J. and Spence, R.J.S. (1981). Simpler tests for lime-pozzolanas. Building Research and Practice. May/June.

Allen, W.J. and Spence, R.J.S. (1983). A study of the activity of a volcanic pozzolana in Northern Tanzania. In Appropriate Building Materials for Low Cost Housing, vol. 1, p.34. Spon, London.

Alston, A.S. (1982). Timbers of Fiji: properties and potential uses. Department of Forests. Suva.

Apers, J., Pletinck, M., Vershcure, H. (1983). A pozzo-lime cement industry in Rwanda. In Appropriate Building Materials for Low Cost Housing, vol. 2, p. 86. Spon, London.

Armstrong, L.D. (1985a). Timber structures: detailing for durability. Timber engineering for developing countries, Part 5. UNIDO Publication UNIDO/10.610. United Nations Industrial Development Organization, Vienna.

Armstrong, L.D. (1985b). Use of green timber in structures. Timber engineeringfordeveloping countries, Part 5. UNIDO Publication UNIDO/10.610. United Nations Industrial Development Organization, Vienna.

ASTM D176-77 (1977). Working Loads for Timber Connectors. American Standard for Testing Materials, USA.

Australian Standard AS 1649 (1974). Determination of Basic Working Loads for Metal Fasteners tor Timber. Standards Association of Australia, Sydney.

Australian Standard AS 1720 (1975). SAA Timber Engineering. Standards Association of Australia, Sydney.

Australian Standard AS 1684 (1979). SAA Timber Engineering, SAA Timber Framing Code. Standards Association ot Australia, Sydney.

Australian Standard AS 2082 (1979). Visually Stress Graded Hardwood for Structural Purposes. National Standards Association of Australia, Sydney.

Australian Standard AS 2269 (1979). Structural Plywood. Standards Association of Australia, Sydney.

Australian Standard AS 2270 (1979). Plywood and Blockboard for Interior Use. Standards Association of Australia, Sydney.

Berhane, Z. (1985). Production of low-cost building materials with emphasis on Portland cement. In Appropriate Building Materials tor Low Cost Housing, vol. 2, p. 176. Spon, London. Blakey, F.A. (1961). Cast gypsum as a structural material. Architectural Science Review, vol. 4, No. 1, p. 6.

Blakey,F.A. (1961). Cast gypsum as a structural material, Architectural Science Review, Vol. 4, No. 1, p. 6.

Bibliography

Boonstra, J.L. (1985). Sisal Cement Handbook. Unpublished report, UNCHS.

Boynton, R.S. (1980). Chemistry and Technology of Lime and Limestone. John Wiley, Chichester.

British Gypsum (1986). The White Book: Technical Manual of Building Products. Nottingham.

BS 890:1972. Building Limes. British Standards Institution.

BS 1191: Part 1: 1973. Specification for Gypsum Building Plasters. British Standards Institution.

BS 5756: 1973. Hardwood Grading Rules. British Standards Institution.

BS 881 and 579: 1974. Nomenclature of Commercial Timbers including Sources of Supply. British Standards Institution.

BS 392:1974. Specification for Clay Bricks and Blocks. British Standards Institution.

BS 1014:1975. Pigments for Portland Cement and Portland Cement Products. British Standards Institution.

BS 4978:1975. Softwood Grading Rules. British Standards Institution.

BS 5247:Part 14:1975. Corrugated Asbestos Cement. British Standards Institution.

BS 12:1978. Specification for Ordinary and Rapid Hardening Portland Cement. British Standards Institution.

BS 402:1979. Specification for Plain Clay Roofing Tiles and Fittings. British Standards Institution.

BS 4624:1981. Methods of Test for Asbestos Cement Building Products. British Standards Institution.

BS 5075:Part 1:1982. Concrete Admixtures. Specification for Accelerating Admixtures, Retarding Admixtures and Water Reducing Admixtures. British Standards Institution.

BS 5268:1985. Structural Design of Timber. British Standards Institution.

BS 5268:Part 5:1985. Preservative Treatment for Structural Timber. British Standards Institution.

BQSF (1975). Lime in Building. British Quarrying and Slag Federation, 14 Waterloo Place, London SW1Y 4AR, U.K.

Building Research Establishment (1972). Timber in Tropical Building. Overseas Building Note No. 146. Department of the Environment, United Kingdom.

Building Research Establishment (1974). Painting Woodwork. BRE Digest 261. HMSO, London.

Building Research Establishment (1985). Timber Drying Manual. BRE, Department of the Environment. HMSO, London.

BRI (1985). Stabilised Soil Bricks. Technical Note No. 4. Building Research Institute, Kingston, Jamaica.

Bullard, A.W. (1987). A field guide to the use of pozzolana as an alternative cement. GATE 2/87.

Bullard, A.W. (1987a). Private communication. Campbell, G.S. and Stevenson, A. (1976). The Drying of Ash Eucalyptus Using Solar Energy as a Heat Source. CSIRO. Division of Building Research. Melbourne, Australia.

CBRI (undated). Three Tier Lime Hydrater. Technical Note. Central Building Research Institute, Roorkee, India.

Chindaprasirt, P. (1983). Low-Cost Cement for Rural Areas. Faculty of Engineering, Khon Kaen University, Thailand.

Chugg, W.A. (1968). Glulam. Ernest Bevin Limited, London.

Cleghorn, W. (ed.) (1979). Stabilised Soil. Strathclyde University, Glasgow.

Collier, J.W. (1967). Wood Finishing. London College of Furniture, United Kingdom.

Collins, M.J. (1985). Light Timber Framing Codes for Developing Countries. UNIDO Expert Group Meeting on Timber Construction. United Nations Industrial Development Organization, Vienna.

Cook, D.J. (1984). Rice Husk Ash Cements: Their Development and Applications. United Nations Industrial Development Organization, Vienna.

Cramer, S. (1979). Gypsum Production: A Manual. Ilha do Maio: Projecto de Gesso. Institüt für Geologie, Berlin

Cramer, S. (1982). Gypsum Production on Malo Island - A New Building Material for Cape Verde? Projecto de Gesso. Institüt für Geologie, Berlin.

CRATERRE (1987) Earth Construction Technologies for Developing Countries. 8 vols. Intermediate Technology Publications, London.

CSTB (1985). Construire en plâtre dans les pays en développement. Extrait du Magazine CSTB No. 36. Centre scientifique et technique du bâtiment, Paris.

Dad, M.M. (1986). Prediction of the suitability of soil for making cement stabilised block as a building material. Habitat Seminar, HBRI.

Dagley, E.E. (1985). Efficient Timber Structures Using Metal Connectors, Timber Engineering for Developing Countries, Part 5. UNIDO Publication UNIDO/10.610. United Nations Industrial Development Organization, Vienna

Dalimier, T. (1986). Pozzolanic cement production in Colombia. MTEC Colloquium, Centre scientifique et technique du bâtiment, Paris.

Dass, A. (1986). Coconut-pitch-ash as a pozzolana. In CIB86 Advanced Building Technology, vol. 5, p. 1255.

Dave, N.G. (1986). Research to practice in construction of all-lime houses. Advanced Building Technology, vol. 5, p. 1271

Desch, H.E. (1981). Timber: Its Structure, Properties and Utilization. MacMillan, London.

Dethier, J. (1982). Down to Earth: Mud Architecture, an Old Idea, a New Future. Thames and Hudson, London.

Easton, D. (1982). The Rammed Earth Experience. Blue Mountain Press, Boulder.

Eldarwish, I.A., and Shehata, E., (1983). The use of blended cement in concrete. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 137, Spon, London.

Erdogan, T.Y. (1986). Material properties and stabilisation for adobe brick production. Middle East and Mediterranean Regional Conference on Earthen and Low Strength Masonry Buildings in Seismic Areas. Middle East Technical University, Ankara.

Etherington, A. B. (1983). Interlocking cement and concrete components for low-cost house construction: the building together experience in Thailand. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 236. Spon, London.

Evans, B. (1986). Understanding Natural Fibre Concrete: Its Applications as a Building Material. Intermediate Technology Publications, London.

Fathy, H. (1973). Architecture for the Poor. University of Chicago Press.

Fire Research Station (1970). Proceedings of Symposium No. 3 - Fire and Structural Use of Timber in Buildings. HMSO, London.

Fitzmaurice, R.F. (1958). Manual on Stabilised Soil Construction for Housing. United Nations, New York.

Food and Agriculture Organization of the United Nations (1975). Proceedings of the World Consultation on Wood Based Panels in New Delhi.

Food and Agriculture Organization of the United Nations (1976). The Marketing of Tropical Wood, Wood Species from African Tropical Moist Forest. Rome.

Food and Agriculture Organization of the United Nations (1978). The Marketing of Tropical Wood, Wood Species from South American Tropical Moist Forests. Rome.

Food and Agriculture Organization of the United Nations (1982). Frame Saw Manual. Forestry Paper 39. Rome.

Food and Agriculture Organization of the United Nations (1983). Circular Saw Manual. Forestry Paper 40. Rome.

Food and Agriculture Organization of the United Nations (1985). Saw Doctoring Manual. Forestry Paper 58. Rome.

Food and Agriculture Organization of the United Nations (1985). Coconut Wood Processing and Use. Forestry Paper 57. FAO, Rome.

Food and Agriculture Organization of the United Nations (1986). Wood Preservation Manual. Forestry Paper 76. FAO, Rome.

Forest Industries Council of Papua New Guinea (1979). Timber Training Manual No. 1: Introduction to Grading. Port Moresby.

Galal, A.F., Shater, M.A., El-Didamony, H. (1983). Portland-basalt mixed cement. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 84, Spon, London.

Gandhi, S. (1986). The Brick Industry in India: Energy Use, Tradition and Development. Ph.D. Dissertation, University of Cambridge.

Government of Fiji, Ministry of Forests (1985). Fiji Pine Code of Practice for Light Timber Frame Buildings not Requiring Specific Design. Suva.

Gram, H.E. (1983). Durability of Natural Fibres in Concrete, Swedish Cement and Concrete Research Institute, Stockholm.

Gram, H.E., Persson, H. and Skarendahl, A. (1984). Natural Fibre Concrete, Swedish Agency for Research and Co-operation with Developing Countries, Stockholm.

GRET (1982). Le plâtre: sa production et son utilisation dans l'habitat. Groupe de recherches et d'échanges technologiques, Dossier Technologies et Développement, Ministère de la Co-operation et du Développement, Paris.

GRET (1985) La chaux: sa production et son utilisation dans l'habitat. Groupe de recherches et d'échanges technologiques, Paris.

Haider, S.Z., Ahmed, A.U., Alam, A.K.M.K., Monie, V. (1986). Management and utilization of waste phospho-gypsum of a TSP factory. Habitat Seminar, HBRI, Dhaka.

Hammond, A.A. (1973). Prolonging the Life of Earth Buildings in the Tropics. Building and Road Research Institute, Kumasi, Ghana.

Hammond, A.A. (1983). Pozzolana cements for low cost housing. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 73. Spon, London.

Hammond, A.A. (1983). Technology alternatives for producing bricks in developing countries. In Appropriate Building Materials for Low Cost Housing , vol. 1, p. 221, Spon, London.

Hammond, A.A. (1986). Mining and Quarrying Wastes Utilisation in Ghana, Ph.D Thesis, University of Eindhoven.

Hill, N.R. (1990). A clamp can be appropriate for the burning of bricks. Appropriate Technology, vol. 7, No. 1.

Holmes, S. (1981). Stabilized soil as an appropriate building material in the Third World. In Appropriate Technology in Civil Engineering. Thomas Telford, London.

Hourdin, H. (1962). La fabrication et l'utilisation du plâtre en climat désertique. Congress Eurogypsum.

Huybers, P. (1984). The Delft Wire Lacing Tool. Centre for International Co-operation and Appropriate Technology, The Netherlands.

IFEC (undated). Stabilised Earth Construction, an Instruction Manual. International Foundation for Earth Construction, 2501 M St NW, Washington DC 20037, USA.

IS:1141 (1958). Code of Practice for Seasoning. Indian Standards Institution.

IS:1725-1960. Specification for Soil-Cement Blocks used in General Building Construction. Indian Standards Institution.

IS:1861-1961. Code of Practice for Manufacture of Lime in Vertical Mixed-Feed Kilns. Indian Standards Institution.

IS:2110-1962. Code of Practice for In-situ Construction of Walls in Buildings with Soil-Cement. Indian Standards Institution.

IS:2858-1964. Code of Practice for Roofing with Mangalore Tiles. Indian Standards Institution.

IS:2542:Part I-1964. Methods of Tests for Gypsum, Plaster, Concrete and Products. Indian Standards Institution.

IS:2700-1964. Code of Practice for Wooden Roof Shingles. Indian Standards Institution.

IS:401-1967. Code of Practice for Preservation of Timber. Indian Standards Institution.

IS:1727-1967. Methods of Tests for Pozzolanic Cements.Indian Standards Institution.

IS:1849-1967. Code of Practice for Design and Installation of Lime Kilns. Indian Standards Institution.

IS:4098-1967. Specification for Lime-Pozzolana Mixture. Indian Standards Institution.

IS:1336-1971. Specification for Cut Sizes of Timber. Indian Standards Institution.

IS:6932-1973. Methods of Tests for Building Limes. Indian Standards Institution.

IS:2117-1975. Guide for Manufacture of Hand-made Common Burnt-clay Building Bricks. Indian Standards Institution

IS:1326-1976. Specification for Non-Coniferous Sawn Timber. Indian Standards Institution.

IS:1489-1976. Specification for Portland-pozzolana Cement. Indian Standards Institution

IS:654-1977. Specification for Clay Roofing Tiles, Mangalore Pattern. Indian Standards Institution.

IS:3812-1981. Specification for Fly Ash for Use as Pozzolana and Admixture. Indian Standards Institution.

IS:1344-1981. Specification for Burnt Clay Pozzolan. Indian Standards Instruction.

IS:712-1984. Specification for Building Limes. Indian Standards Institution.

IS:1077-1986. Specification for Common Burnt Clay Building Bricks. Indian Standards Institution.

Janssen, J.J.A. (1982). Bamboo in Building Construction. Eindhoven, University of Technology.

Junta del Acuerdo de Cartegra (1984). Manual de Clasificación Visual para Madera Estructural. Lima.

Kafescioglu, R. (1984). Conclusions of the Research for Gypsum Stabilised Adobe (Alker) and an Application. International Colloquium on Earth Construction Technologies Appropriate to Developing Countries, Brussels.

Kafescioglu, R., Gurdal, E., Guner, A., Akman, M.S., (1983). Adobe blocks stabilized with gypsum. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 3. Spon, London.

Kapur, P.C. (undated). ASHMOH Cement, Department of Metallurgical Engineering. IIT, Kanpur.

Kapur, P.C. and Sai, A.S.R. (1980). ASHMENT Cement. IIT, Kanpur.

Kateregga, J.K. (1983). Improvement and use of earth construction products for low cost housing. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 23. Spon, London.

Keating, W.G. (1985). Specification of Timber for Structural Use, Timber Engineering for Developing Countries. Part 5 of UNIDO Publication UNIDO/10.610. United Nations Industrial Development Organization.

Keddie, J. and Cleghorn, W. (1980). Brick Manufacture in Developing Countries. Scottish Academic Press.

Kenya Bureau of Standards (1987). Specifications for Fibre Concrete Roofing Tiles, K502-749. Unpublished draft.

Khadi and Village Industries Commission (undated). Lime Kiln Designs. Bombay.

Khadi and Village Industries Commission (1975). Lympo. Bombay.

King, G.A. (1979). Gypsum Products and their Application in the Australian Building Industry. Symposium on New Building Materials and Components, Baghdad.

Launchbury (1971). Handbook of Fixings and Fastenings. Architectural Press, London.

Lew Wing Hing (1983). Rubberwood. Malaysian Timber Marketing Conference, 6-7 December, 1983, Malaysian Timber Industry Board, Malaysia.

Lola, C.R. (1985). Fibre Concrete Roofing: Evaluation of Field Experiences. AT International.

Lopez, H.O. (1974). Nuevos Tecnicos de Construcción con Bambu, Estudios Technicos Colombianos, Liml Eada, Colombia.

Lumley, T.G. and Choong, E.T. (1979). Technical and economic characteristics of two solar kiln designs. Forest Products Journal, vol. 29, No. 7.

Majumdar, N.C. and Hiralal, E.S. (1982). Energy Saving in Firing of Building Bricks. CBRI, Roorkee.

Malaysian Timber Industry Board (1984). The Malaysian Grading Rules. Kuala Lumpur.

Mathur, G.C. (1987). Durability and service life of mud houses. In Building Materials for Low Income Housing. Spon, London.

McHenry, P.G. (1984). Adobe and Rammed Earth Building. John Wiley, Chichester. Meredith, B. (1987). Personal communication.

Middleton, G.F. (1975). Building Your Own House of Earth, Compendium Pty, Australia.

Mindham, C.N. (1986). Roof Construction. Collins, London and Glasgow.

Ministry of Foreign Affairs, New Zealand (1976). Coconut Stem Utilization. Seminar Proceedings held in Kingdom of Tonga. Wellington.

Mohammed, A. and Iqbal, M.Z. (undated). Gypsum in Unit Masonry Construction and Plaster Works. Building Research Station, University of the Punjub, Lahore.

Moine, M. and Quaranta, R. (1986). Five years of social housing in Mayotte, MTEC Colloquim. Centre scientifique et technologique du bâtiment, Paris.

Montrey, H.M. (1982). Engineering Structural Panels for Light Framed Construction. Weyerhausor Company, Tacoma. Mukerji, K. (1986). Soil Block Processes. GATE/GTZ, Eschborn.

National Particleboard Association (1980). MDF for Interior Use, ANSI A 208.2. American National Standards Institute.

Nguyen Tien Dich (1987). The use of local building materials for low-income housing in Vietnam. Appropriate Technology for Low-Cost Housing. Bangkok.

Nigerian Standards Organisation (1976). Specification for Burnt Clay Building Units. Nigerian Standard 74:1976.

Nolhier, M. (1986). Construire en plâtre. L'Harmattan, Villes et Entreprises, Paris.

Norton, J. (1986). Building with Earth: a Handbook. Intermediate Technology Publications, London.

Norton, J. (1987). Limitations on improving earthquake resistance: the exploitation of local materials. A case study in Guinea-Conakry. In Building Materials for Low-cost Housing. Spon, London.

NZS CP4 (1953). Code of Practice for Timber Preservation. New Zealand Standards Association.

NZS 53604 (1984). Code of Practice for Light Timber Frame Buildings not Requiring Specific Design. New Zealand Standards Association.

OCRS (1982). Le plâtre dans la construction au Sahara. Organisation commune des régions sahariennes, Algiers.

Ollis, J. (1973). The Classification of Wood Based Methods and Systems. The Architects' Journal. Architectural Publications, London.

Pagtambayayong (1984). Progress Report on Pozzolanic Cement Binder Project 1983/84. Unpublished.

Papua New Guinea, Department of Primary Industry (1976). Shake and Shingle Manual. Office of Forests.

Parry, J.P.M. (1979). Brickmaking in Developing Countries. Building Research Establishment, Watford.

Parry, J.P.M. (1985). Fibre Concrete Roofing. Parry and Associates, Cradley Heath.

Philippines Coconut Authority (1979). Coconut Wood. The Proceedings, Manila and Zamboanga, 22-27 October, 1979.

Plumtre, R.A. (1980). Some thoughts on design and control of solar timber kilns. Wood Drying Workshop, IUFRO, Division V Conference, Madison, Wisconsin.

Plumtre, R.A. (1985). Solar Drying Kilns for Sawnwood, Forest Products Abstracts Review Article, vol. 8, No. 2. Commonwealth Forestry Bureau, Oxford.

Plywood Association of Australia (1980). Plywood in Residential Construction.

Plywood Association of Australia (1982). Structural Plywood Bracing - Design Manual

PPCT (undated). Le liant pozzolanique LIPORWA, characteristiques et emploi. Ruhengeri, Rwanda.

Prakash, S. and Ahmed, F.U. (1983). Use of rice husk as fuel for firing building bricks. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 252. Spon, London.

Rai, M. (1985). Appropriate building materials for low cost housing. In Appropriate Building Materials for Low Cost Housing, vol. 2, p. 118. Spon, London.

Read, W.R., Choda, A. and Cooper, P.I. (1974). A solar timber kiln, Solar Energy, vol. 15. London.

Rosen, H.N. and Chen, P.Y.S. (1980). Drying Lumber in a Kiln with External Solar Collectors.

Sakula, J.H. (1982). Sisal Cement Roofing in East and Southern Africa. Unpublished report. Intermediate Technology Development Group, Rugby.

Sakula, J.H. and Sauni, J. (1980). Oldonyo Sambu Pozzolime Industry: History, Operation and Development. SIDO, Dar-es- Salaam.

Salas, J., Castillo, P., Sancher de Rojas, M.I. and Varco, J. (1986). Pilot study for the industrial production of RHA, MTEC Colloquim. Centre scientifique et technologique du bâtiment, Paris.

Schilderman, J. de A.L. (1985). Vers l'utilisation du liant pozzolanique dans l'habitat informel. COOPIBO, Hexenlee, Belgium.

Schilderman, T. (1985a). The Case of a Lime-Pozzolana Industry in Rwanda: the PPCT. Unpublished report. COOPIBO, Rwanda.

Schreckenbach, H. and Abankwa, J.G.K. (1984). Construction Technology for a Tropical Developing Country, GATE/GTZ, Eschbom.

Selker, J. and Childer, L. (undated). Clay Tile Manufacture: A Guide. Technical Note. Intermediate Technology Development Group, Rugby.

Serry, V. (1970). Metrication in Timber and Allied Building Trades. Ernest Benn Limited, London.

Shresta, R. (1986). Setswana Cement. Unpublished report.

SKAT (1987). Fibre Concrete Roofing (FCR). SKAT/IT Publications, London.

Smith, R.G. (1974). Gypsum. R.J.S. Spence (ed.), Lime and Alternative Cements. Intermediate Technology Publications, London.

Smith, R.G. (1981). Improved moulding devices for hand-made bricks. Appropriate Technology, vol. 7, No. 4.

Smith, R.G. (1982). Small scale production of gypsum plaster for building in the Cape Verde Islands. Appropriate Technology, vol. 8.

Smith, R.G. (1984). Rice Husk Ash Cement, Progress in Development and Application. Intermediate Technology Publications, London.

Spence, R.J.S. (1970). A Study of the Use of Soil-Cement in Building. Report BR2, National Council for Scientific Research, Lusaka.

Spence, R.J.S. (1976). Alternative Cements in India. Intermediate Technology Development Group, Rugby.

Spence, R.J.S. (1980). Small-Scale Manufacture of Cementitious Materials. Intermediate Technology Publications, London.

Spence, R.J.S. and Cook, D.J. (1984). Building Materials in Developing Countries. John Wiley, Chichester.

Spence, R.J.S. and Cook, D.J. (1984a). Gypsum, lime and pozzolans. Chapter 6 in Building Materials in Developing Countries. John Wiley, Chichester.

Spence, R.J.S. and Sakula, J. (1981). Pozzolime as an alternative cementing material. In Appropriate Technology in Civil Engineering, Thomas Telford, London.

Spiropoulos, J. (1985). Small-Scale Production of Lime for Building in Developing Countries : A Guide to Project Design and Implementation. GATE, Eschborn.

Strefford, J. and McMurdo, G. (1978). Woodwork Telchnology. Schofield and Sims Limited, United Kingdom.

Suain, H. (1982). Tessalit: le plâtre au Mali. Direction nationale de l'urbanisme et de la construction. Ministère des transports et des travaux publics, République du Mali et United Nations Centre for Human Settlements (Habitat),, Nairobi.

Subrahmanyam, B.V., and others, (1983). A new low energy intensive building material based on lateritic soils for low cost housing in developing nations. In Appropriate Building Materials for Low Cost Housing, vol. 1, p. 18. Spon, London.

Thomas, D.W. (undated). Small Scale Manufacture of Burnt Building Brick. Volunteers in Technical Assistance, Washington, D.C.

Timber Research and Development Association (1985). Timber Stress Grading, Analysis of Existing Timber Strength Grouping and Strength Classification Systems. Paper 10/WG 447/2. UNIDO Expert Group Meeting on Timber Construction. Vienna.

TRADA (1984). Basic Sizes of Softwoods and Hardwoods. Wood Information Sheet 15. Timber Research and Development Association, High Wycombe.

TRADA (1984a). Stress Grading Rules for Tropical Hardwoods and Conifers. United Nations Industrial Development Organization, Vienna.

TRADA (1985). Finishes for Exterior Timber. Timber Research and Development Association, High Wycombe.

TRADA (1985a). Timber Stress Grading: Analysis of Existing Timber Strength Grouping and Strength Classification Systems. Paper 10/WG 447/2. UNIDO Expert Group Meeting on Timber Construction. Vienna.

TRADA (1987). Timber for External Cladding. Wood Information Sheet 20. Timber Research and Development Association, High Wycombe.

Tschernitz, J.L. and Simpson, W.T. (1979). Solar heated forced air lumber dryer for tropical latitudes, Solar Energy, vol. 22.

Turkish Institute of Standards (1977). Adobe Blocks and Production Methods. TS 2514:1977. Ankara.

United Nations (1964). Soil Cement: Its Use in Building. United Nations publication. Sales No. 64.IV.6. New York.

United Nations (1972). The Use of Bamboo and Reeds in Building Construction. United Nations publication. Sales No. E.72.IV.3. New York.

United Nations Centre for Human Settlements (Habitat) (1985). The Use of Selected Indigenous Building Materials with Potential for Wide Application In Developing Countries (HS/83/85/E).

United Nations Centre for Human Settlements (Habitat) (1986). Innovative Building Materials Production and Utilization in Lusaka, Zambia. Project Monograph. Nairobi.

United Nations Centre for Human Settlements (Habitat) (1987). Standards and Specifications for Soil Blocks, Burnt-clay Bricks, Lime, Pozzolanas and Fibre-concrete Roofing. ARSO/CSC/UNCHS Workshop on Formulation of Standards and Specifications for Local Building Materials. Nairobi.

United Nations Development Programme (1983). Appropriate Vertical Shaft Lime Kilns in Indonesia, UNDP/UNIDO Building Materials Project in Indonesia (INS/74/034). Ceramic Research and Development Institute, Indonesia.

United Nations Industrial Development Organization (1978). Brick Making Plant: Industrial Profile.

United Nations Industrial Development Organization (1985). Popular Manual for Wooden House Construction. United Nations, New York.

United Nations Industrial Development Organization (1985). Timber Engineering for Developing Countries, Part 1 to Part 5. Document Nos. UNIDO/10.606, UNIDO/10.607, UNIDO/10.608, UNIDO/10.609 and UNIDO/10.610. Vienna.

United Nations Industrial Development Organization (1986). Lime in Industrial Development: A UNIDO Guide to its Uses and Manufacture in Developing Countries. UNIDO/IS.555. Vienna.

United Nations Industrial Development Organization (1987). Mini lime plants: technology profiles. To be published.

United Nations Industrial Development Organization and International Labour Office (1984). Small-Scale Brickmaking, Memorandum No. 5 UNIDO IS.456. Vienna.

United Nations Industrial Development Organization and International Labour Office (1987). Stabilised Soil Blockmaking. Technical memorandum. Vienna.

United States Agency for International Development (undated). Handbook for Building Homes of Earth. Office of International Affairs, Washington, D.C.

United States Department of Agriculture (1974). Wood Handbook. USDA Agriculture Handbook No.72. Washington, D.C.

United States Department of Commerce (1973). Voluntary Product PS 58-73 - Basic Hardboard. National Bureau of Standards, Washington, D.C.

University of Canterbury (1976). Pole Housing Design and the Environment: Notes from the Seminar, 17-18 February. Christchurch.

University of Canterbury (1977). Pole Housing Design and Practice: Notes from the Seminar, 9-10 May. Christchurch.

Vildoso, A. and Monzon, F.M. (1984). Seguir Construyendo con Tierra. CRATERRE, Lima.

Volunteers In Technical Assistance (1975). Making Building Blocks with the CINVA Ram Press, Intermediate Technology Publications, London.

Volunteers In Technical Assistance (1977). Lime Production in Honduras. Washington, D.C. Walford, G.B. (1982). Round timber connections. New Zealand Timber Design Society Newsletter. June.

Whale, L.R.J. (1986). Design of Timber Structures in Buildings, Seminar on Effective Use of Timber. Government of Brunei Darussalam, Bandar Seri Bagawan.

Wingate, M. (ed.) (1985). Small-Scale Lime-burning, Intermediate Technology Publications, London.

Wong, W.C. and Ong, C.L. (1979). The production of particleboard from rubberwood. Malaysian Forester.